



Wastewater Energy Management

Best Practices Handbook

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1 Introduction

The New York State Energy Research and Development Authority (NYSERDA) promotes energy efficiency and the use of renewable energy sources. These efforts are key to developing a less polluting and more reliable and affordable energy system for all New Yorkers. Collectively, NYSERDA's efforts aim to reduce greenhouse gas emissions, accelerate economic growth, and reduce customer energy bills. Governed by a 13-member board, NYSERDA has provided objective information and analysis, technical expertise, and support in New York State since 1975. The stated mission and vision of NYSERDA are as follows:

- Advance innovative energy solutions in ways that improve New York State's economy and environment.
- Serve as a catalyst—advancing energy innovation, technology, and investment; transforming the State's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

With this charge, NYSERDA identified the municipal wastewater sector as a target to strategically reduce energy consumption in New York State.

1.1 Background

The primary goal of the wastewater sector has been to meet regulatory requirements for the protection of human health and the environment. The sector has focused on maintaining compliance with discharge requirements regulated by the New York State Department of Environmental Conservation (DEC) through the New York State Pollutant Discharge Elimination System (SPDES) program. Historically, to ensure achievement of this primary objective, many facilities within the wastewater sector were not designed to operate with a goal of reducing or optimizing energy use.

A secondary goal of the wastewater sector is to provide services for reasonable and fair user fees or rates. These fees are typically developed based on the debt service for capital improvements, operating expenses (labor, energy, chemical, etc.) and reserve accounts. Many wastewater utilities treat energy costs simply as a cost of doing business, without significant effort to effectively mitigate cost increases. As a result, capital reserves are often depleted to offset rising operating expenses in an effort to maintain stable user fees. Funding operations in this manner leaves the utility vulnerable to unforeseen capital expenditures and may result in inadequate investment in the upkeep, maintenance, and upgrade of process equipment and facilities, or cause utilities to base all equipment purchases solely on initial capital cost, rather than considering the life-cycle cost of owning and operating the equipment.

1.2 Description of New York State's Wastewater Sector

In New York State, municipal wastewater utilities provide services to nearly 95% of the State's population. The municipal wastewater sector includes 702 water resource recovery facilities (WRRFs) with a combined design treatment capacity of 3.7 billion gallons per day (DEC 2004).

NYSDERDA conducted statewide assessments of energy use by New York State's wastewater sector in both 2003/2004 (Yonkin, 2008) and 2012/2013 (ENER7C13a, Andrews, 2015). On an aggregate basis, statewide energy use (total kilowatt-hours per year; kWh/year) and normalized energy use (kWh per million gallons; kWh/mg) have increased over the almost decade between studies, despite lower flows and nearly level biochemical oxygen demand (BOD) loads. The increase is due to more stringent nutrient removal standards, which have triggered modifications at several large plants, and double-digit percentage declines in flow at more than 100 of the 189 plants with average design flow greater than one million gallons per day. A summary of pertinent results from both studies are presented in Table 1.

Table 1. Energy Used by Wastewater Treatment Sector in New York State

Plant Size Category (Based on Design Flow)	Number of WRRFs ^a	2003/2004			2012/2013		
		Energy Use (kWh/mg)	% of Treatment Capacity	% of Electric Energy Use	Energy Use (kWh/mg)	% of Treatment Capacity	% of Electric Energy Use
Statewide average	-----	1,755 ^c	-----	-----	1,800	-----	-----
< 1 mgd	520	4,620 ^b	4	11	-----	5	12
1 - 5 mgd	106	2,200 ^c	7	8	2,300	6	8
5 - 20 mgd	43	1,740 ^b	13	14	1,970	12	12
20 - 75 mgd	19	1,700 ^b	24	27	1,370	22	19
> 75 mgd	14	1,100 ^b	52	40	1,280	55	49

a Source: DEC 2004 Descriptive Data

b Source: Yonkin, M; 2008.

c Source: Andrews, N, Willis, J, Nascimento, D; 2015

1.3 Overview of New York State's Clean Energy Goals

New York State's Clean Energy Standard (CES) is the most comprehensive and ambitious clean energy goal in the State's history. The CES is designed to fight climate change, reduce harmful air pollution, and ensure a diverse and reliable low-carbon energy supply. Reforming the Energy Vision (REV) is New York State's strategy to develop a clean, resilient, and affordable energy system for all New Yorkers. This comprehensive effort sets the State on a realistic path to achieving its long-term environmental and economic development goals, including the Clean Energy Standard commitment that will require 50% of electricity to be sourced from renewable energy sources by 2030. Other components of REV include groundbreaking regulatory reform and leading by example through public investment in energy efficiency and renewable energy.

The Clean Energy Fund (CEF) supports the CES commitment by reducing the cost of clean energy and accelerating the adoption of energy efficiency to reduce load while increasing renewable energy to meet demand. Among other solutions, the CEF offers to reduce greenhouse gas emissions through increased efficiency and use of renewable energy. NYSERDA continues to collaborate with all sectors, including wastewater, to collectively identify and address critical barriers to energy efficiency and clean energy.

1.4 Current Trends Affecting Energy Use in Wastewater Sector

Recent updates have been implemented to SPDES permits for WRRFs across the State that require disinfection, have more stringent limits for nitrogen forms, or enforce the reduction of combined or separate sewer overflows (CSO/SSO). While these stringent limits are being enforced by the DEC to protect the waters of New York State, WRRFs that need to maintain compliance with their newly issued permits may see an increase of energy use with the installation of ultraviolet (UV) disinfection systems, larger blower power consumption for nitrification, additional flow being treated that was previously discharged during wet weather events, or installation of solids and floatable materials control equipment that had not previously existed.

WRRFs are encouraged to seek the most energy-efficient system when installing new equipment; for example, by following the recommended best practices provided in this handbook and considering the life-cycle cost of new projects (see Appendix C: Economic Evaluation Methods). Proposed projects applying for funding through the New York State Environmental Facilities Corporation (EFC) are required to identify energy efficiency measures, energy costs and payback, and comply with EFC's endorsement of energy reduction in the wastewater sector.

Climate change and extreme weather events are causing municipalities to implement resiliency plans through the protection of equipment and relocation of key process components. Additional pumping to higher ground surface elevations might be introduced to avoid the risk of flooding but introduces additional use of energy. Another component of resiliency plans is typically a strategy for reduction of greenhouse gases (GHG), either direct (e.g., fuel use) or indirect (e.g., electricity use), which ties back into New York State's clean energy goals and REV.

1.4.1 Resource Recovery and Emerging Technologies

WRRFs no longer just treat water and generate waste as a by-product, but recover resources that are embedded in wastewater, such as energy, renewable natural gas (biogas), nutrients, and clean water. Added benefits of energy and biogas recovery are the reduction in quantity of solids disposed of in landfills, pathogen reduction in biosolids, and reduction in fossil fuel extraction. Nutrients recovery offsets the manufacture and application of synthetic fertilizers, while reducing nutrients discharged to waterways.

There are a few proprietary technologies that can be used to recover dissolved phosphorus from digested sludge and digester supernatant to produce a marketable mineral fertilizer. The first step of these processes is biological or chemical phosphorus removal from wastewater to transfer phosphorus to the sludge. Next, chemical treatment is used to form a phosphorus mineral, such as struvite, that can be sold to generate revenue.

Biogas generated by anaerobic digesters contains approximately 60% methane. The remaining components are carbon dioxide, water, and other impurities such as hydrogen sulfide and siloxanes. Biogas can be treated to separate methane from the other constituents. The resulting product is relatively pure methane that meets quality standards of pipeline natural gas, also called renewable natural gas (RNG), which qualifies under the Renewable Identification Number (RIN) program when used for vehicle fueling. Petroleum producers are obligated to meet a certain quota of RINs, so there is a trading market for them, from which the WRRF can have an economic benefit. Economic incentives can also be associated with recovering renewable energy from the WRRF, in the form of Renewable Energy Certificates (RECs), which can be sold to create a supplemental revenue stream in addition to the avoided cost for purchasing electricity that is generated with the recovered biogas.

Some promising new technologies are being researched to reduce energy use in systems that are currently energy intensive. For example, shortcut nitrogen removal uses anaerobic ammonium oxidizing (anammox) bacteria that convert ammonia to nitrogen gas without the requirement of additional air or carbon. This system has application in sidestreams such as nitrogen-loaded anaerobic digester supernatant and dewatering waste, as well as mainstream systems.

Post Aerobic Digestion (PAD) is the addition of an aerobic digester following the anaerobic digestion process. PAD provides additional destruction of volatile solids, improving dewatering performance and reducing the volume of disposed biosolids. It also can remove ammonia and organic sulphur compounds (a source of odors). The PAD process increases annual aeration costs but eliminates the need for a separate sidestream treatment process to manage nitrogen and can reduce some ortho-phosphorus by forming struvite as the reactor pH increases.

Another emerging technology in digester enhancement is waste activated sludge (WAS) hydrolysis, which is a process where the cell walls of the bacteria contained in WAS are ruptured (lysed). The process can be accomplished by mechanical, thermal, chemical, or pressure-based means or a combination of several of these methods. The process offers many advantages, such as increased solids retention time (SRT) and reduced digester heating loads; improved digestibility, resulting in enhanced biogas production; and improved dewaterability resulting in reduced volumes of disposed biosolids.

Aerobic granular sludge is a proprietary innovative biological wastewater treatment technology that provides simultaneous BOD, nitrogen, and phosphorus removal in a reduced-volume footprint. Low energy requirements are associated with increased tank depth that increases aeration efficiency, elimination of return sludge, and nitrate recycle streams and elimination of mixing. The process is still in its relative infancy but has been tested in a sequencing batch reactor process with success.

An emerging technology that is at the forefront of the dynamic changes occurring in New York State's energy sector is energy storage. Water utilities, which operate using energy day and night to move and treat water, can install batteries to store energy overnight, when energy is cheaper, and tap into that power during the daytime, when power is more expensive. This also helps the electric grid meet demand during peak hours by enabling the WRRF to use battery storage to offset a portion of its daytime energy use.

1.5 Purpose

The wastewater sector's primary objectives remain unchanged—meeting regulatory requirements and protecting public health. However, with rising energy costs, a greater financial burden placed on local governments, and a public sentiment toward sustainability and resiliency, improving energy efficiency and optimizing energy management at WRRFs (one of the larger energy users under the control of a typical municipality) are paramount.

Energy efficiency and the protection of public health and the environment are not mutually exclusive. Often, energy conservation programs not only reduce the amount of energy utilized at a facility, but also provide improved control and operation of unit treatment processes—satisfying both the wastewater sector's primary and secondary objectives.

The purpose of this Wastewater Energy Management Best Practices Handbook is to provide the wastewater sector with guidance on the development of an energy conservation program, implementation of capital and operational improvements to reduce energy consumption, and methods to track performance and assess program effectiveness.

2 Energy Management Program Development

2.1 Understanding Energy Management Opportunities

Wastewater utilities are tasked with the mission of minimizing the costs associated with protecting water resources while maintaining a high degree of reliability. In part, these can be addressed by the following:

- Improving energy efficiency and managing total energy consumption
- Controlling peak demand for energy
- Managing energy cost volatility
- Improving energy reliability

Good energy management practices avoid unanticipated costs, maximize all possible energy and cost savings opportunities, and often overlap with other utility best management practices. For example, an effective preventive maintenance program improves motor efficiency and also increases system reliability. Similarly, improvements to the overall efficiency of wastewater treatment enhance energy performance as measured by some energy benchmarks or key performance indicators, such as gallons of water treated per kilowatt-hour of electricity consumed. Good energy management practices can also have ancillary benefits, such as enhanced staff communications and morale, increased public perception, and a more comprehensive understanding of the treatment process. Ancillary benefits should always be taken into consideration when evaluating prospective energy management opportunities.

Conventional wastewater treatment is intrinsically energy intensive, due in part to the need to deliver large volumes of oxygen via high-horsepower blowers to support the secondary treatment process. Pumping, which is also core to the treatment process of most WRRFs, is also an inherently energy intensive process. One of the biggest drivers for improving energy efficiency is often cost, which is based on two main components, the quantity of electricity used and the demand for electricity. The next sections provide greater detail on both components.

2.1.1 Improving Energy Efficiency and Managing Total Energy Consumption

The quantity of electricity is measured in kilowatt-hours and reflects the amount of physical “work” that can be performed by the electricity. Electric utility rates typically include an energy consumption charge that is based on the number of kilowatt-hours consumed per billing cycle, and often the charge is further subdivided by “on-peak” versus “off-peak” consumption, where on-peak rates are higher than off-peak rates. Understanding the electric utility’s pricing policies, or rate structures, is critically important to planning energy management programs that provide the greatest financial benefit. A detailed discussion of electric utility rates, bills, and kilowatt-hours is provided in Appendix A.

WRRFs can, and should, set energy reduction goals, whether it be a small goal to partially reduce electric consumption and costs or a more aggressive goal to become a net zero energy or carbon neutral facility. The amount of energy used by a utility for wastewater treatment is a function of various factors, including topography of the service area, system size, treatment process, type and condition of equipment, regulatory requirements, and operation and management (O&M) practices. Since no treatment system operates at 100% efficiency, opportunities exist at all WRRFs to improve energy efficiency and reduce the total consumption of kilowatt-hours.

An example of an energy conservation measure that focuses on improving energy efficiency would be more closely matching blower and motor size to oxygen demand in the WRRF's secondary treatment system. Blowers are often sized based on the maximum capacity required at peak conditions and have limited turndown capability to match the more frequently occurring average or minimum air requirements, which may vary based on hourly influent loading and temperature conditions. Overall design parameters might have changed since the original WRRF design due to unrealized growth projections, decreases in local population, or changes in industrial contributions. If the existing blower has sufficient turndown capability, automated controls that adjust the blowers' airflow based on actual oxygen demand can help provide the right amount of air (and energy) from the blowers. However, if blowers are limited in their turndown, then a new blower solution may be warranted. Similarly, in some situations the diffusers, either due to fouling or a less efficient design, are the greatest source of inefficiency in an aeration system, requiring significantly greater air to deliver the same amount of useable oxygen. In those situations, replacement of the diffusers may be a more appropriate first step.

2.1.2 Controlling Peak Demand for Energy

Electric utilities typically include a "demand charge" in their rate structure that can account for anywhere from 30 to 60% of the overall cost of electricity for a typical WRRF. The demand charge is based on the customer's maximum demand for electricity (kilowatts) measured during a billing period and allows the electric utility to recover the capacity costs required to meet each customer's maximum energy needs.

From the electric utility's perspective, a high degree of variability in customer demand is the most difficult situation to plan for and requires a large investment in capital. Consequently, electric utilities will reward customers that can demonstrate a low variability in electric demand over time, or "flattened" demand curve. This includes two separate but related goals:

- Minimizing changes in peak demand throughout the course of a billing period.
- Shifting loads from peak periods, typically during daylight hours, to "off-peak" periods.

Wastewater utilities can realize significant savings in electric costs by minimizing demand charges. Sometimes this can be done indirectly by reducing the variability in demand placed on their own systems, through measures such as addressing infiltration and inflow, or providing equalization for industrial loadings and feeding them to the aeration tanks over a longer period of time to flatten aeration demands during peak periods. Other strategies focus on shifting loads to off-peak periods or

flattening demand by minimizing the overlap between treatment processes. Conducting intermittent dewatering operations during off-shifts is an example of this.

2.1.3 Managing Energy Cost Volatility

The price of energy, including electricity, natural gas, and fuel, can vary significantly from day to day, or year to year. However, wastewater utility revenues are less variable by nature, and therefore dramatic changes in energy costs can severely stress utility budgets and disrupt other programs.

From a utility management perspective, protecting against volatility in costs is an important goal that should not be overlooked or undervalued in the energy planning process. Wastewater utilities have a variety of strategies available to protect against volatile energy prices. Examples include the long-term procurement of energy, and provisions for alternative energy sources and/or on-site generation of energy.

2.1.4 Improving Energy Reliability

As many local and system-wide power outages have proven in the past, energy, like money, water, or air, becomes noticeably more important when it is unavailable. Good design practices, as well as State statutes require wastewater utilities to provide critical systems with adequate backup power. The energy planning process should also identify opportunities to improve energy reliability whenever possible.

Reliability improvements can include protection against complete loss of power, as well as identifying changes in power quality (e.g., under voltage, power harmonics, or power surges) that can damage equipment, or instituting operating procedures to address changes in power availability. On-site distributed generation systems are an obvious opportunity to enhance reliability.

In recent years, the New York Independent System Operator (NYISO), the organization responsible for coordinating electrical demand throughout the State, has also offered various opportunities for large customers of power to participate in demand management programs. Customers are generally required to have generators rated 100 kilowatts (kW) or higher, or to be capable of reducing at least 100 kW of load. These programs are designed to heighten regional power reliability, while offering participating customers a revenue source in exchange for curtailing their energy use during high-demand periods by transferring load to on-site electricity generating resources.

2.1.5 Opportunities for Renewable Energy

WRRFs with a permitted flow rate larger than 5 million gallons per day (mgd) have a significant potential to generate electricity and heat from biosolids. WRRFs with lower permitted flow rates also have the potential to generate electricity and heat from biosolids if they combine these with high-strength organics from outside generators or consolidate solids handling operations with other small utilities.

WRRFs treating sludge in anaerobic digesters can set a goal of using biogas in a combined heat and power (CHP) system to generate electricity that can be used to offset the on-site power demand and heat to offset the digester heating requirement. WRRFs already recovering energy from biogas can explore accepting high-strength waste in co-digestion to boost biogas production to maximize utilization of existing resources and capacity or to help drive expansion of on-site recovery activities.

Energy generation from renewable resources such as wind and sun can be an additional distributed energy generation opportunity for those who have on-site biogas-fired CHP, or a new opportunity for WRRFs that do not have anaerobic digesters or where installation of a CHP is not cost-effective.

Energy from Biogas

Biogas, or anaerobic digester gas, is a byproduct of anaerobic digestion and contains 60 to 65% methane. Biogas can be recovered to generate electricity and heat for on-site use. Typical CHP technologies are internal combustion engines, microturbines, gas turbines, and fuel cells. Alternatively, the biogas can be used directly as boiler fuel for the production of heat. Specific digesters and biogas parameters as well as the impact of CHP on other treatment systems, cost of electricity, and the potential for air regulations should be considered to assess the feasibility of installing a CHP system. This practice is widely accepted and has been employed for years by WRRFs throughout New York State, the United States, and the world.

More recent applications of biogas recovery include scrubbing the biogas of contaminants and CO₂ to obtain a gas that is relatively pure methane and meets the quality standards of pipeline natural gas that can be accepted by the gas utility. This renewable natural gas could also be used for vehicle fuel.

Energy from Photovoltaic Systems

Solar or photovoltaic (PV) systems are seeing widespread installation throughout New York State's residential, commercial, industrial, institutional and municipal sectors. Modest growth has been seen in the installation of PV systems at WRRFs, but greater opportunity remains. PV can be particularly attractive because it does not rely upon or interfere with the WRRFs processes, but rather, takes advantage of large unused spaces such as building roofs, tank covers, or relatively flat, sun-exposed land in between structures or within buffer lands surround utility assets. Costs for PV systems have decreased through the years, making this renewable energy option more cost-effective. The use of alternative ownership structures (e.g., land leases with power purchase agreements) can be used to help capitalize upon available tax credits and other exemptions that may have little to no value to a tax exempt entity like a wastewater utility, but provide value to private developers who can potentially pass along a portion of the savings to the utility in the form of lower power purchase rates. It is important to recognize that power purchase agreements often last 15 years or longer. So, thoughtful location of PV resources is needed to avoid encroaching upon existing infrastructure or limiting additional expansion that may be needed to meet treatment requirements over the duration of the PV system's useful life.

Energy from Wind

Wind turbines can be installed at WRRFs to generate power from wind, operating up to 24 hours per day in areas with naturally occurring consistent winds. The location for a wind turbine needs to be

unobstructed and away from human or vehicle traffic and outside of any flight paths. While the footprint of wind turbines is substantially less than that for the same capacity of PV, most wind turbines have substantial visual effects because of their height. Accordingly, if a wind turbine is considered, it is important that stakeholders within the surrounding area are engaged in the siting of the project. Like PV, the use of a power purchase agreement with a third-party private developer may allow a utility to more effectively realize tax benefits offered by distributed renewable generation. Also, like PV, siting requires thoughtful planning and long-term needs should be considered.

2.2 Basic Steps Involved in Building an Energy Program

This section outlines an eight-step approach to developing an effective energy management program.

2.2.1 Step 1: Establish Organizational Commitment via Strategic Energy Management (SEM)

Strategic Energy Management (SEM) applies the principles of continuous improvement to create a long-term holistic approach to managing energy that fosters substantial long-term savings. SEM is a process of evaluating existing energy management practices and implementing opportunities to optimize energy use at a WRRF.

SEM begins with identifying an energy champion, an individual who's passionate about reducing energy consumption and will lead the implementation of SEM at the WRRF. The energy champion will develop an energy team, a cross-functional group of WRRF management, technical, and operations staff who have diverse knowledge of WRRF processes and practices and are authorized to make operational and procedural changes. A strategically-selected and enthusiastic team is critical to the success of SEM, as is utility management support. The basic components of SEM are as follows:

- Measuring and tracking energy use to help inform strategic business decisions
- Driving managerial and corporate behavioral changes around energy
- Developing mechanisms to track and evaluate energy optimization efforts

Visit NYSERDA's website at nysERDA.ny.gov/All-Programs/Programs/Strategic-Energy-Management for additional information on Strategic Energy Management. In addition, visit www.aceee.org for information on Strategic Energy Management via the website for the American Council for an Energy-Efficient Economy.

2.2.2 Step 2: Develop Baseline Energy Use

Understanding where, why, and when energy is used is a critical component of sound energy management. Studies have shown that the process of investigating energy use and improving energy awareness among staff, may result in measurable energy efficiency gains (~ 3–5%). The following list summarizes the actions required to develop an energy use baseline:

- **Gather basic information.** One year of data should be analyzed at a minimum to identify any seasonal patterns, but three or more years of data is ideal so that any trends or anomalies can be identified. Data sources can include utility billing records, supervisory control and data acquisition (SCADA) system records, O&M records, submetering or data logging records, and equipment/motor lists with horsepower and load information.
- **Organize treatment processes by functional area.** Identifying logical functional groups makes performance measurement and benchmarking easier and will also facilitate planning for separating energy loads to manage demand. Additionally, maintaining a treatment process or system approach may also help to identify opportunities or potential conflicts that are missed if equipment is considered on a standalone basis.
- **Evaluate energy bills and understand the energy rate structure.** Many energy management strategies are directly linked to the pricing of energy, and it is critical to understand how the “energy rate structure” impacts energy costs, as well as what other options are available. It can be helpful to reach out to the power utility (most larger accounts are assigned a representative) or a consultant for this step.
- **Assess the connection between changes in hydraulic loading and energy use.** Hydraulic data (i.e., flow) should also be assembled to understand patterns of demand and correlations between flow and energy use. Analyze data at several time frames to identify diurnal patterns, seasonal patterns, and correlations between wet weather flows and energy demand. Where available, energy use per pound of organics treated (e.g., BOD or Total Kjeldahl Nitrogen (TKN)) can also be a very effective metric to assess performance and identify trends.
- **Build a basic model to organize data and capture energy use patterns.** Typical models used in this stage of the process can be created using a generic spreadsheet, or for larger utilities it may be helpful to purchase specific software for organizing energy data. An example of a basic spreadsheet model is provided in Appendix B. The level of modeling sophistication can range from a basic motor list relating horsepower to energy demand to a time-varying (dynamic) model that combines flow, process, and rate structure information that predicts hourly demand and energy costs under various scenarios. The process of modeling can help to identify what types of information are most helpful, the limitations on currently available information, and what data needs to be gathered in the field. In addition, an energy use model can be a valuable tool for testing theories, validating the owner/manager’s understanding of energy use, calculating performance metrics, and visualizing and communicating energy use patterns.

- **Create basic graphics and reports to communicate initial findings.** Although this is an early step in the process, it can produce some valuable insights that should be shared with a wider audience than the energy management team.

2.2.3 Step 3: Evaluate the System and Collect Data

Whereas an energy use baseline is developed primarily from historical records, this step relies on real-time data and input from operations/maintenance staff. The following list summarizes the actions required to perform this step:

- **System walk-through.** Verify equipment lists, operating status, and motor sizes for major utility systems; begin with equipment/processes that have been identified as most energy intensive during the baselining process.
- **Staff interviews.** Build understanding of operating practices, maintenance practices and history, regulatory and engineering limitations, operational priorities, and collect suggestions for energy conservation opportunities.
- **Gather energy performance data.** Fill gaps in the energy model with field data, which may include direct measurements using a current meter, tracking average equipment run times of motors throughout the day, or utilizing a more sophisticated sub-metering system or temporary data logging to gather energy use data.
- **Benchmark energy performance.** Identify useful performance measures and calculate energy use in comparison with utility performance data. Examples include: kilowatt-hours per million gallons treated, comparison of peak demand (kilowatts; kW) with peak pumping rates (gallons per minute; gpm), or energy use measures based on contaminant removal (kilowatt-hours per pound of BOD removed). Performance metrics can be compared internally to historical data or engineering design criteria or can be used for external benchmarking in comparison to similar facilities.
- **Update the energy use model.** Make any improvements and/or corrections in the energy use model using newly gathered field data and observations. This may include refining assumptions about the load, set points, or time of use for various motors.

2.2.4 Step 4: Identify Energy Efficiency Opportunities

Energy efficiency opportunities can be any system change that helps achieve a stated energy management goal. The initial goal is to identify as many opportunities as possible. Ideas for energy efficiency opportunities can come from a variety of sources, including reference materials, success stories from similar utilities, interviews with staff, consultant recommendations, or discussions with energy providers.

Categorizing energy efficiency opportunities can help to organize a large amount of information into a manageable format. For example, energy efficiency opportunities can be grouped by process area or by the implementation approach used, such as the following:

- Capital program or equipment replacement
- Process change
- Operational change
- Automation or controls
- Maintenance improvements
- Business measures

2.2.5 Step 5: Implement No- and Low-Cost Opportunities

Some of the energy efficiency opportunities identified require no or a low-level of capital investment. These opportunities are primarily oriented towards operational or cultural changes. Such opportunities should be implemented first; and information about these strategies should be shared broadly. Typically, no- and low-cost opportunities are found through the following suggestions:

- Identify operations that are performed for no reason except because it's always been done that way and determine whether the routine performance still produces beneficial outcomes.
- Assess current treatment flows/loads to identify those that are much smaller than their designed values and determine whether redundant/larger equipment/process tanks can be taken offline.
- Identify equipment that operates continually and ascertain whether it should be operated intermittently.
- Evaluate set points for automated controls and confirm they are still appropriate for actual operating conditions or if daily or seasonal adjustment might provide energy savings.

2.2.6 Step 6: Prioritize Remaining Opportunities for Implementation

Once no- and low-cost opportunities have been identified, the remaining opportunities should be prioritized based on meeting the WRRF's energy management goals, economic viability, and ability to implement without creating a high-level of risk or conflict. The prioritization process typically involves some type of economic evaluation method such as payback period or life-cycle costs. Examples of various economic evaluation methods are provided in Appendix C. The prioritization process may also require site-specific evaluation criteria to evaluate benefits such as reduced risk of process failure or improved operator safety.

2.2.7 Step 7: Develop an Integrated Capital/Energy Plan

Once energy efficiency opportunities are identified, the next step is planning for implementation. Similar to a business plan, the implementation plan should clearly communicate the actions to be performed, resources required, and outcomes anticipated from the projects. The following list summarizes the actions required to complete the step:

- List the candidate energy efficiency opportunities chosen for implementation and describe the goals and objectives of the improvement.
- Explain the resources needed, including a budget and financing plan.
- Develop any specifications needed, including design criteria and procurement-related documents.
- Provide any changes in standard operating procedures and/or process control strategies.
- Set the schedule for implementation, including milestones and gaining the necessary regulatory approvals (if applicable). To the extent practicable, integrate larger energy advancement measures as incremental add-ons to already planned capital projects rather than creating multiple, smaller standalone capital projects. For smaller advancement measures, consider using reserve funding or incorporating energy efficiency considerations into traditional maintenance or procurement processes.

2.2.8 Step 8: Track and Report Success

Project success should be measured and documented at each phase of implementation with specific performance metrics identified in advance of implementation. Documentation should include information on impacts to process performance, operations and maintenance, and staff. Project success must be communicated, especially to anyone involved in allocating funding for future projects and the staff responsible for implementing the project. Communication of project success is often overlooked, but it is critical to continuous improvement for the following reasons:

- Encourages continuous adjustments until a process is optimized
- Provides rationale for future decision making
- Provides impetus to engage staff in continuous improvement

2.3 Constraints to Implementing an Energy Program

Most engineering decisions are made within the context of trade-offs or counterbalancing constraints. Awareness and understanding of constraints are required for good energy planning and decision-making.

Typical constraints on energy enhancements include the following:

- Organizational constraints
- Capital costs
- Process reliability
- Regulatory requirements and limits
- O&M capabilities and non-energy O&M costs
- Engineering constraints
- Space availability

3 Energy Management Best Practices

The Energy Management Best Practices section of this guidebook is divided into four categories:

- Renewable Distributed Generation
- Organizational Energy Management
- Treatment Process Energy Management
- Building Systems Energy Management

Renewable Distributed Generation Best Practices describe practices for generating on-site energy to reduce a WRRF's reliance on grid-supplied power. In addition to generation of on-site power from photovoltaic or wind systems, one unique aspect of the wastewater sector is the potential for on-site electrical and thermal energy generation using anaerobic digester gas, a by-product of the anaerobic sludge digestion process. Additionally, for some WRRFs the deployment of hydroelectric generation may also be feasible.

Organizational Energy Management Best Practices describe management/planning practices applicable to the overall facility. General approaches to develop an energy plan, educate facility personnel, and manage electric bills are included in this section.

Treatment Process Energy Management Best Practices describe design and/or operations practices applicable to wastewater treatment and collection systems. Best practices for optimizing pumps, aeration systems, and solids handling processes are included in this section.

Building Systems Energy Management Best Practices describe design and/or operations practices applicable to managing building system energy use. HVAC and lighting systems generally provide the most opportunities for building-related energy efficiency improvements.

Each Best Practice can be used as a stand-alone document. Best Practices applicable to similar processes are referenced under the "Additional Information" sections in the following tables.

As a supplemental NYSERDA resource, visit nyscrda.ny.gov/About/Publications/Research-and-Development-Technical-Reports/Water-and-Wastewater-Technical-Reports for technical reports on wastewater.

3.1 Renewable Distributed Generation Best Practices

R1—Generate Energy from Biosolids

Best Practice	Biogas produced by anaerobic digesters (AD) can be used as a fuel to generate electricity via combined heat and power (CHP) systems (e.g., reciprocating engines, microturbines, combustion turbines, fuel cells). The thermal energy generated by CHP systems can often be recovered and used to meet digester heat loads and/or for space heating. Alternatively, biogas can be used directly as boiler fuel; or processed and injected into the natural gas pipeline; or used to fuel fleet vehicles.
Additional Information	WW 34—Optimize Anaerobic Digester Performance, R2—Increase Energy Generation with Co-Digestion of Source-separated Organics.
Primary Area/Process	Anaerobic sludge digestion.
Productivity Impact	For existing AD systems, gas piping should also exist; therefore, relatively minimal impact is expected during installation of a CHP system. If construction of new AD system is required, impacts to operations could be significant.
Economic Benefit	Biogas-to-electricity systems are typically cost-effective options for WRRFs having an average influent flow greater than 5 mgd with, or planning to install, AD systems. Biogas-to-electricity systems may also be feasible for smaller WRRFs, if import of feedstocks or consolidation of solids handling operations with other WRRFs is possible (see R2). For smaller WRRFs with existing AD systems, processed biogas may also be injected into the pipeline or used to fuel fleet vehicles.
Energy Savings	A common assumption made for AD systems is that for each 4.4 mgd of typical strength municipal influent treated, the quantity of biogas produced will generate approximately 100 kW of electricity and 12.5 MMBtu of thermal energy. When used in boilers, biogas typically provides 550 to 650 Btu per scfm.
Applications and Limitations	The moisture content and concentration of hydrogen sulfide (H ₂ S) in digester gas influences both the economic and technical feasibility of a CHP system. High H ₂ S concentrations result in engine corrosion; in which case it may be necessary to install gas scrubbers. Most CHP system suppliers claim that concentrations higher than 1000 ppm would necessitate the installation of a gas scrubber. Other trace compounds, such as siloxanes, can also cause deleterious effects to combustion devices and should also be removed through gas treatment.
Practical Notes	Reciprocating engines are appropriate for most WRRFs. Microturbines and fuel cells are typically smaller capacity; multiple units can be installed to increase capacity. Microturbines are particularly relevant where emissions are a concern. Combustion turbines can be used for larger capacity systems (greater than 1 MW. For larger WRRFs with existing incinerators or biogas-fired steam systems, steam turbines are a viable technology. Organic Rankine Cycle systems can be also be used to generate electricity via waste heat from treatment process or primary generating systems.
Other Benefits	Beneficial use of biogas eliminates venting/flaring, which emit greenhouse gases.
Stage of Acceptance	Combined heat and power systems are gaining popularity in the wastewater sector.

R2—Increase Energy Generation with Co-Digestion of Source-Separated Organics

Best Practice	Co-digestion of sludge with other high-strength organic wastes (e.g., restaurant grease, vegetable/fruit processing waste, municipally-derived food scraps) can significantly increase biogas production. Co-digestion also maximizes use of AD system capacity and may create a revenue stream for the WRRF.
Additional Information	R1—Generate Energy from Biosolids
Primary Area/Process	Anaerobic sludge digestion.
Productivity Impact	High-strength organic wastes are high in volatile fatty acids, which rapidly convert to biogas. Co-digestion with high-strength wastes results in increased biogas production. Increased sludge viscosity, due to increased concentration of total solids, may impact the efficiency of mixing and pumping operations. Co-digestion of FOG may result in the formation of a scum layer if not effectively mixed. Foaming or other process upsets could result, depending on the characteristics of the added feedstock. Waste receiving facilities may need to be built. Thickening, dewatering, and disposal will also be needed to manage the increase in solids.
Economic Benefit	Receipt of high-strength wastes may generate revenue via collection of tipping fees and additional power generation due to increased biogas production. Diversion of FOG from collection systems may reduce maintenance costs.
Energy Savings	By diverting high-strength wastes directly to an AD system, secondary system energy use should not be impacted. Depending on available digester capacity and volume of high-strength waste added, increased biogas production can support transition of the WRRF to net zero energy. Larger volume of solids may create economies of scale that make upgrade to more energy efficient technologies viable.
Applications and Limitations	Construction of additional facilities, such as a waste receiving station, mixed equalization tank, pretreatment or pre-processing facilities, or pumping, may be required. If improperly stored, grease or dairy waste may generate odors. Operational changes may be needed to handle additional solids (i.e., increased duration of intermittent dewatering operations). Digester mixing capacity should be evaluated before embarking on a co-digestion project.
Practical Notes	Source-separated wastes may be contaminated by inert debris (e.g., rocks, silverware, plastic wrappers). Pre-consumer waste often has less debris and unanticipated contamination. High-strength waste should be introduced slowly to a healthy AD system to avoid process upset. New wastes should be fully characterized before added to an AD system. Pilot testing may be warranted to avoid unforeseen operational problems. Impacts to downstream solids handling processes, existing solids disposal methods, and wet stream processes needed to treat side streams associated with the digestion and dewatering processes should be fully understood.
Other Benefits	Diversion of source-separated wastes and FOG from landfills and collection systems. Increased production of biogas that can be used for electrical generation, as a fuel for thermal systems or vehicles, or injected into the natural gas pipeline.
Stage of Acceptance	Co-digestion has been successfully proven at full-scale.

R 3—Install Wind Generation System

Best Practice	Sited correctly, the installation of one or more wind turbines can provide a reliable, albeit intermittent, source of renewable electricity generation. Coupled with electricity storage, wind generation can be relied upon to provide a stable source of renewable electricity that is independent of the other treatment operations occurring at a WRRF.
Additional Information	None
Primary Area/Process	Wind generation is not directly associated with a given process or area. Typically wind generation is most applicable when installed in large open areas on the WRRF property or satellite properties that are owned by the wastewater utility or municipality.
Productivity Impact	No impact on treatment processes when sited correctly. Some disturbance of plant operations may occur during construction. Maintenance and upkeep of wind turbines is likely outside of the normal skill set of WRRF operations and maintenance staff.
Economic Benefit	Electricity generated by one or more wind turbines would be more cost-effective than grid-supplied electricity, reducing a WRRF's electricity costs.
Energy Savings	Electricity generated by the wind turbine(s) can be used to offset grid-supplied electricity with a source of renewable distributed generation.
Applications and Limitations	The opportunity for wind generation varies significantly dependent upon electric utility and State. A number of options are available to acquire renewable electricity ranging from on-bill purchase of renewable energy through a WRRF's existing electric utility to on-site generation to entering into a direct third-party power purchase agreement with or without an equity stake in the wind generation assets.
Practical Notes	Construction for large-scale wind generation requires substantial land space to maintain setbacks from adjacent properties and, because of visual effects and technical aspects of wind generation (noise and vibration, height, potential wildlife impacts, and shadow flicker) may require significant public engagement and permitting prior to construction. Tax credits and depreciation approaches that can enhance the financial viability of a wind generation project may not be available to tax-exempt entities, making Power Purchase Agreements with a third-party taxable entity potentially more financially attractive for either on-site or off-site wind generation facilities. For WRRFs that own substantial off-site land to support land application activities, wind generation may offer a means to provide additional benefit with the same property. Wind turbines and farming activities are able to effectively co-exist.
Other Benefits	Electricity generation using a renewable resource like wind reduces greenhouse gas emissions associated with electricity usage at a WRRF.
Stage of Acceptance	A number of WRRFs utilize wind generation (on and off site) to meet a portion of their electricity needs. Wind generation as a technology is widely accepted and has a proven track-record of successful operation.

R 4—Install Solar Photovoltaic Generation System

Best Practice	The installation of a solar photovoltaic (PV) electricity system can provide a reliable, albeit intermittent, source of renewable electricity generation. Coupled with electricity storage, PV generation can be relied upon to provide a stable source of renewable electricity that is independent of the other treatment operations occurring at a WRRF.
Additional Information	None
Primary Area/Process	PV generation is not directly associated with a given process or area. Large-scale solar systems will typically be installed in large open areas on the WRRF property or satellite properties that are owned by the wastewater utility or municipality. Smaller scale solar systems can be constructed on existing roofs, as canopies over tanks or parking, or as small, rack-mounted arrays throughout a WRRF site.
Productivity Impact	No impact on treatment processes when sited correctly. Some disturbance of plant operations may occur during construction. Maintenance and upkeep of solar arrays is likely outside of the normal skill set of WRRF operations and maintenance staff.
Economic Benefit	Electricity generated by one or more solar arrays would be more cost-effective than grid-supplied electricity, reducing a WRRF's electricity costs.
Energy Savings	Electricity generated by the solar array(s) can be used to offset grid-supplied electricity with a source of renewable distributed generation.
Applications and Limitations	The opportunity for PV generation varies significantly dependent upon electric utility and State. A number of options are available to acquire renewable electricity ranging from on-bill purchase of renewable energy through a WRRF's existing electric utility to on-site generation to entering into a direct third-party power purchase agreement with or without an equity stake in the PV generation assets.
Practical Notes	Construction of large-scale PV generation requires substantial land space to accommodate the solar array and to maintain setbacks from adjacent properties. Tax credits and depreciation approaches that can improve the financial viability of a PV generation project may not be available to tax-exempt entities, making Power Purchase Agreements with a third-party taxable entity potentially more financially attractive for either on-site or off-site solar generation facilities. For WRRFs that own substantial off-site land to support land application activities, PV generation may offer a means to provide additional benefit with the same property by constructing solar arrays on the less useable portions of the property. If solar arrays are constructed on rooftops, be sure to consider the structural integrity and longevity of the roof system. When PV systems are constructed over tanks or near building exhausts, consider potential impacts of gases and vapors that may be present.
Other Benefits	Electricity generation using a renewable resource like solar reduces greenhouse gas emissions associated with electricity usage at a WRRF.
Stage of Acceptance	A number of WRRFs utilize PV generation (on and off site) to meet a portion of their electricity needs. Solar generation as a technology is widely accepted and has a proven track-record of successful operation.

3.2 Organizational Energy Management Best Practices

01–Facility Energy Assessments

Best Practice	An annual energy survey should be performed annually to assess opportunities for energy efficiency. The survey should include all energy consuming processes.
Additional Information	None
Primary Area/Process	This practice should be completed for the entire facility, with emphasis on the major energy using processes (i.e., pumping, aeration, solids management).
Productivity Impact	There may be short-term disturbances during implementation of opportunities.
Economic Benefit	Payback period varies depending on the complexity of the modifications and any required capital investment.
Energy Savings	Energy savings vary depending on the existing equipment and the opportunities identified. Savings typically range from 10 to 50% of the total system energy consumption. Several projects have resulted in energy savings of as much as 65%.
Applications and Limitations	None
Practical Notes	Energy can be saved at every facility, regardless of treatment process, age, or size.
Other Benefits	May result in overall operational improvements as WRRF strives for additional savings.
Stage of Acceptance	Acceptance of the value of energy assessments is growing. The acceptance varies depending on opportunity (i.e., technology, practice).
Resources	<p>The EPA offers the Portfolio Manager tool for benchmarking WRRFs, an interactive web-based system that allows WRRFs to track and assess energy consumption and carbon footprint. The tool is appropriate for primary, secondary, and advanced treatment plants with or without nutrient removal; and is applicable to WRRFs having design flows of at least 0.6 mgd. After inputting the following information, the tool produces an energy use score for the facility, which is relative to the scores of a national population of WRRFs. The score is expressed on a scale of 1 to 100.</p> <ul style="list-style-type: none"> • 12 consecutive months of energy data • Average influent flow rate • Plant design flow rate • Average influent biological oxygen demand (BOD5) • Average effluent biological oxygen demand (BOD5) • Presence of fixed film trickle filtration process • Presence of nutrient removal process <p>The tool can be accessed through the following link: http://www.energystar.gov/index.cfm?c=eligibility.bus_portfoliomanager_eligibility</p>

O 2–Real Time Energy Monitoring

Best Practice	An accurate, real-time energy monitoring system permits the collection and analysis of 15-minute energy data for each treatment process and pump installation. This support tool enables utility staff and management to establish energy use reduction goals and monitor/verify demand consumption.
Additional Information	None
Primary Area/Process	This technology can be applied to all process treatment units and is most beneficial to high-energy users. High-energy users may include large facilities and/or facilities that utilize an inordinate amount of energy or demand per unit of water conveyed and treated.
Productivity Impact	No impact on a facility's capability to meet treatment limits.
Economic Benefit	Payback depends on the cost of the monitoring system and on the system's adjustment capability.
Energy Savings	The achievable range of energy savings is typically 5 to 20% where energy efficiency is viewed as a daily performance goal.
Applications and Limitations	Each site must be individually assessed to identify which processes can benefit the most from monitoring.
Practical Notes	The most common barrier to implementation is acquiring management approval and commitment for the capital expenditure. Be sure to include the potential savings from energy management in payback calculations. This practice has been suggested in benchmark studies.
Other Benefits	Monitoring also supports other functions, such as maintenance and the identification of failing equipment.
Stage of Acceptance	This concept is well known but not widely practiced since it is usually not necessary for meeting system performance goals (effluent limits).

O 3–Energy Education for Facility Personnel

Best Practice	All wastewater system personnel should understand the relationship between energy efficiency and facility operations. Information can be found in various publications, including this handbook and through training sessions offered through organizations such as NYSERDA.
Additional Information	None
Primary Area/Process	This practice focuses on personnel, especially those who make both long- and short-term decisions that affect energy use (including elected officials). All parties involved in the operation of a wastewater conveyance and treatment facility can benefit from understanding their system’s energy use.
Productivity Impact	None
Economic Benefit	There is no direct return on investment for this practice. The return will be a function of actual process changes made in response to recommendations.
Energy Savings	The energy savings for this practice vary substantially depending on what measures are implemented.
Applications and Limitations	None
Practical Notes	It is useful to establish an annual schedule for energy training to keep facility management and personnel up to date on available technology and management practices.
Other Benefits	Staff members and colleagues within the industry typically share and discuss the information they gain from attending education classes and reading publications.
Stage of Acceptance	Education and training are common and widely accepted throughout the industry.

O 4—Comprehensive Planning Before Design

Best Practice	Clearly define utility goals and objectives and set the design criteria for system improvements. Incorporate all appropriate energy efficiency best practices into capital and operations enhancement plans. This helps the utility address the critical needs of the future system and optimizes capital and operating budgets.
Additional Information	None
Primary Area/Process	All components of wastewater treatment systems.
Productivity Impact	None
Economic Benefit	Payback varies by facility and by project, depending on the energy benefits and costs of alternative designs and operations. Payback may vary from a few months to several years.
Energy Savings	Future energy savings are derived from the incorporation of energy efficiency practices in the capital and operations improvement plans.
Applications and Limitations	There are no limitations on this practice because comprehensive planning should occur prior to project development.
Practical Notes	Proactive and open communications promote the success of capital and operations improvement planning, including energy management planning. Aggregating energy efficiency measures into a capital enhancement project and justifying them in the aggregate, helps avoid lost opportunities for future energy savings. Energy saving improvements should be evaluated on a life-cycle cost basis.
Other Benefits	Well-conceived and planned projects result in the highest value to the utility.
Stage of Acceptance	Increasingly, utilities are seeing the value of energy management. Its acceptance is growing, especially as a means to stretch limited budgets.

O 5—Design Flexibility for Today and Tomorrow

Best Practice	Operation, administration, and management personnel need to be involved with the planning and design of any improvements and/or expansions to their system. Take into account any significant anticipated changes when designing enhancements or expansions that have the flexibility to serve both current and future system needs.
Additional Information	None
Primary Area/Process	All components of wastewater systems.
Productivity Impact	Impact should be negligible.
Economic Benefit	The selected design of any improvements or expansions should reflect the best quality for the most reasonable cost. The simple payback for installing smaller operating units and storage that can follow current system demand—compared with a larger, single unit operating at reduced capacity—is usually one to five years.
Energy Savings	Energy savings vary by project but are directly related to a system’s ability to closely meet demands at all points throughout its lifetime, as opposed to being designed only for 20-year peak flows.
Applications and Limitations	None
Practical Notes	An assessment of the size and space needed to install multiple smaller units, as compared to one or two large units, is required. Also, the continuous operation of smaller unit(s) puts less stress on a system than a large unit operating periodically.
Other Benefits	A system that operates effectively as well as efficiently through the life of its design, not just at its future design condition, is a value to the system operations.
Stage of Acceptance	Designers and owners are becoming more knowledgeable and accepting of equipment sized to match existing conditions, as opposed to only considering projected peak-design needs.

O 6—Electric Peak Reduction

Best Practice	<p>Management of peak demand (shifting to off-peak or shaving peak-power usage) can substantially lower energy costs. The following can be done to optimize power use and reduce electric peak demand:</p> <ul style="list-style-type: none"> • Assess electric bills to understand peak-demand charges and examine facility operations to determine ways to avoid or reduce peak demand. • Develop an operation strategy that meets overall system demand and minimizes pumping and specific treatment processes during peak-power demand periods. Consider adding storage capacity or simply delaying the time of operation. • Assess the typical and peak operation of your wastewater system to identify areas where peak-power demand can be trimmed or shifted.
Additional Information	O 7—Manage Electric Rate Structure; WW 5—Idle or Turn off Equipment
Primary Area/Process	All energy-using components of wastewater systems with a focus on the supply side. Candidates for off-peak operation include (1) biosolids management (operation of sludge presses), (2) recycling, (3) loading or feeding anaerobic digesters—so supernatant does not recycle on-peak, (4) operate mixers or aerators in aerobic digesters, and (5) accept or treat hauled-in wastes.
Productivity Impact	None
Economic Benefit	Paybacks are typically less than a year because the modifications are generally procedural and do not have significant costs.
Energy Savings	Energy consumption savings (kilowatt-hours) are generally minor. Savings result from reduced demand for peak power.
Applications and Limitations	Application may be limited by the amount of storage available and by the absolute minimum power requirement for necessary operations. Substantial savings are more likely with a time of use (TOU) rate. Smaller facilities may not be charged separately for demand.
Practical Notes	An understanding of the relationship between peak-power demand and the demands of wastewater treatment are also necessary to make the application effective.
Other Benefits	Improved utilization of system components.
Stage of Acceptance	Electric utilities provide information to assist customers with optimizing their consumption according to their specific rate structures. Most wastewater utilities are aware of this but may not be optimizing their operations to fit the rates.

O7—Manage Electric Rate Structure

Best Practice	Work with your utility account manager to review your facility's electric rate structure. The review process should determine if the current structure is the most appropriate pricing for your facility based on peak demand and overall energy consumption.
Additional Information	O 6—Electric Peak Reduction
Primary Area/Process	Facility wide with special attention to accounting and purchasing.
Productivity Impact	None
Economic Benefit	There is no direct return on investment for this practice. However, economic benefit can result from actual process changes made in response to recommendations.
Energy Savings	The energy savings vary with site and rate structure.
Applications and Limitations	All facilities should apply this practice.
Practical Notes	All personnel should be aware of how their facility is charged for energy consumption.
Other Benefits	Management gives more attention to the operation of a system when energy awareness is made available to everyone.
Stage of Acceptance	The practice of reviewing utility bills and rate structures is becoming more common as its value becomes recognized. As wastewater personnel are becoming more aware of energy costs and methods of billing, modifications to operations are also being made.

O 8—Certification Programs—LEED, Envision, BREEAM

Best Practice	<p>The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a voluntary, consensus-based rating system for developing high-performing, sustainable buildings. LEED is applicable to all building types and emphasizes state-of-the-art strategies in five areas: sustainable site development, water savings, energy efficiency, materials and resources selection, indoor environmental quality. Projects must typically include energy efficiency measures to qualify for LEED certifications.</p> <p>Envision is a rating system and best practice resource to help evaluate the sustainability of civil infrastructure. Envision rates six infrastructure types: energy, water, waste, transport, landscape, and information.</p> <p>The Building Research Establishment Environmental Assessment Method (BREEAM) is a sustainability assessment method that is used to masterplan projects, infrastructure, and buildings. BREEAM focuses on nine sustainable categories: energy, land use and ecology, water, health and wellbeing, pollution, transport, materials, waste, and management.</p>
Additional Information	None
Primary Area/Process	<p>LEED is applicable to all areas of building construction, location, and energy. LEED is comprehensive, encompasses many measures, and relies on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and other sources for some of its best practices.</p> <p>Envision is applicable to all areas of a project including design, planning, construction, and maintenance. Rating categories include quality of life, leadership, resource allocation, natural world, climate and risk.</p> <p>The Building Research Establishment sets standards for environmental performance of buildings through design, specification, construction, and operation phases; and can be applied to new or refurbished developments. BREEAM is part of The Code for a Sustainable Built Environment.</p>
Productivity Impact	None
Economic Benefit	Proportional to energy savings achieved.
Energy Savings	<p>LEED: Energy must be reduced by specified amounts for each LEED qualifying areas.</p> <p>Envision: Energy ratings are assigned based on percentage reductions.</p> <p>BREEAM: Energy reductions are the heaviest weighted of the nine categories.</p>
Applications and Limitations	Projects should be reviewed to assess value of applying for LEED, Envision, or BREEAM ratings.
Practical Notes	None
Other Benefits	N/A
Stage of Acceptance	LEED was established in 1998 and is used extensively throughout the world. Envision was established in 2012 and is primarily used in North America. BREEAM was established in 1990 and is primarily used in Europe.

3.3 Treatment Process Energy Management Best Practices

WW 1—Operational Flexibility

Best Practice	<p>Evaluate facility loadings and become familiar with the treatment systems in order to identify, plan, and design the most efficient and effective ways to operate your system.</p> <p>This may include the following:</p> <ul style="list-style-type: none"> • operating fewer aeration tanks • installing variable frequency drives so equipment operation can match system loadings • installing dissolved oxygen monitoring and control equipment • idling an aeration tank during low-flow periods • reducing airflow to the aeration tanks during low-load periods (usually nights and weekends) • waiting to recycle supernatant during lower-flow periods, avoiding periods of high-organic loading • operating diffusers or recycling backwash water during off-peak power demand periods.
Additional Information	<p>WW 9—Electric Motors: Variable Frequency Drives Applications; WW 2— Staging of Treatment Capacity; WW 3—Manage for Seasonal/Tourist Peaks; WW 4—Flexible Sequencing of Basin Use; WW 19—Optimize Aeration System; WW 22—Dissolved Oxygen Control</p>
Primary Area/Process	<p>This practice applies to secondary treatment processes, all pumping operations, and biosolids management.</p>
Productivity Impact	<p>Implementation usually involves changes to operations so there should be little or no impact on production.</p>
Economic Benefit	<p>Payback is generally within two years since most of the modifications are operational and do not incur significant capital costs.</p>
Energy Savings	<p>Energy savings vary depending on the adjustment. A typical range is from 10 to 25%.</p>
Applications and Limitations	<p>All facilities should implement this practice to save on operating costs.</p>
Practical Notes	<p>This practice is best implemented with a committed energy management plan as described in the first section of this handbook and where the flexibility of facility operations is feasible.</p>
Other Benefits	<p>Operations personnel gain a better understanding of the capabilities of the treatment system they control.</p>
Stage of Acceptance	<p>Many facilities accept the need to adjust operations responsive to loadings after learning the magnitude of savings available.</p>

WW 2—Staging of Treatment Capacity

Best Practice	When planning improvements, wastewater system personnel and designers should develop a team approach wherein they determine how modifications will effectively and efficiently meet current and projected conditions. Staging upgrades in capacity can help optimize system response to demand and also reduce energy costs.
Additional Information	WW 1—Operational Flexibility
Primary Area/Process	Staging is most applicable to the major energy users in a system, typically the secondary treatment process, pumping and biosolids management.
Productivity Impact	Usually a system operates most efficiently when loaded nearer to its design load; therefore, staged systems generally function more efficiently as the system grows.
Economic Benefit	The simple payback period is usually less than two years because minimal modifications are required to implement staging.
Energy Savings	Proper staging of treatment capacity can achieve a savings of 10 to 30% of the total energy consumed by a unit process.
Applications and Limitations	Staging is applicable to all systems.
Practical Notes	Usually staging is a minor impact on construction and scheduling in exchange for the energy savings realized.
Other Benefits	Improved control of the system.
Stage of Acceptance	Staging of treatment capacity is gaining acceptance within the wastewater industry; however, it is not readily adopted because of the belief that the entire system must be constructed immediately, rather than efficiently staging a system and bringing components online as needed.

WW 3—Manage for Seasonal/Tourist Peaks

Best Practice	Flexible system design allows a utility to adjust and operate more efficiently during peak-tourist loadings as well as during the off-season. In many areas tourism-related loadings versus off-season may reach as high as 10:1. This may require removing the aeration tanks used during tourist season from service during the off-season.
Additional Information	WW 1—Operational Flexibility
Primary Area/Process	Primary area of focus is the secondary treatment process aeration system.
Productivity Impact	No productivity impact other than brief interruptions while new equipment is installed or placed into operation, if needed.
Economic Benefit	Most retrofit aeration modifications have paybacks of four to six years. If the concept is integrated into the design of new construction, the payback should be less.
Energy Savings	Savings vary but can reach 50% during the off-season.
Applications and Limitations	This application is appropriate for systems that have highly differentiated seasonal loading conditions and where it makes economic sense. The physical sizing of an aeration tank may limit feasibility.
Practical Notes	This strategy needs to be carefully analyzed to ensure that adequate treatment can be provided during the tourist season. The aeration tanks must be sized so they can be taken offline during the off-season. It helps to have several years of facility loading data and utility bills to assess seasonal variation to define the on- and off-peak seasons and the respective peak loadings for proper sizing of equipment.
Other Benefits	If the secondary treatment process is improved, generally the functions of other processes also improve.
Stage of Acceptance	These concepts are well known, understood, and widely accepted.

WW 4—Flexible Sequencing of Basin Use

Best Practice	The selection of basin sizes can have a large impact on the energy consumed at a facility during its lifetime. The facility design team should review the existing and projected organic loadings to identify the best selection of tank sizes. Typically, the use of smaller sized basins is beneficial so that initial loadings can be near the capacity of a smaller basin. The remaining basins can then be loaded sequentially until design capacity is met. This approach allows for energy efficient operation from start up to design flow conditions.
Additional Information	WW 1—Operational Flexibility
Primary Area/Process	Secondary treatment processes, particularly activated sludge treatment facilities.
Productivity Impact	None
Economic Benefit	Payback for constructing multiple tanks depend on space availability at the site. Implementation can be as simple as adding an interior wall to subdivide an existing tank, which can provide a two- to three-year payback. Payback may take three to five years for major site modifications.
Energy Savings	Energy savings of 15 to 40% are common if multiple smaller tanks are available to step the system into operations, compared with having only two large tanks.
Applications and Limitations	All facilities should consider operational flexibility to ensure the management of ever-changing facility loads.
Practical Notes	Facility personnel should work closely with designers throughout the design process. Information on the sizes and operation of basins required for a treatment process is invaluable. Operating more fully loaded smaller tanks versus operating larger, under-loaded tanks is preferable. Using intermediate tank walls (division walls) may be a simple, acceptable solution.
Other Benefits	Improves overall operation of the facility.
Stage of Acceptance	Acceptance varies from site to site based on facility staff preferences and experiences with maintenance of empty tanks.

WW 5—Idle or Turn off Equipment

Best Practice	Idle or turn off non-essential equipment when feasible, especially during periods of peak-power demand. Review operations and schedules to determine if any equipment is not required for the proper operation of the facility.
Additional Information	O 6—Electric Peak Reduction
Primary Area/Process	This technology can be applied to almost all areas in a wastewater system.
Productivity Impact	None
Economic Benefit	Paybacks are typically short, if not immediate, because the modifications are low or no-cost changes in procedures.
Energy Savings	Savings depend on the amount of non-essential equipment currently operating. Reduced power demand also results if shutoff occurs during periods of peak-power demand.
Applications and Limitations	Care must be taken to not turn off an essential piece of treatment or monitoring equipment or warning system device. Provide as much automatic control (such as timers) as feasible to reduce the need for operator attention and the potential for operator error. This practice should not undermine compliance with design conditions and regulatory requirements.
Practical Notes	It is useful to ask why each piece of equipment operates and if the equipment is critical to operation. This is of particular value when trying to reduce peak-power demand charges.
Other Benefits	Increased equipment life, reduced maintenance, and possibly fewer spare parts required.
Stage of Acceptance	Wastewater utilities are increasingly more willing to turn off equipment once it is understood that system requirements can still be met.

WW 6—Electric Motors: Install High-Efficiency Motors

Best Practice	Survey existing motors for possible replacement with new, high-efficiency motors and specify the most energy-efficient motors on all new installed and inventoried equipment. Include an emergency motor replacement program that specifies energy-efficient motors.
Additional Information	WW 7—Electric Motors: Automate To Monitor and Control; WW 9—Electric Motors: Variable Frequency Drive Applications; WW 10—Electric Motors: Correctly Size Motors
Primary Area/Process	Can be applied to all electric motors, especially on those wastewater facility motors with high-annual operating hours and those that operate during peak demand (e.g., aeration blowers, disinfection systems, pumps and clarifiers).
Productivity Impact	None, except for a possible short shutdown time for removal of the existing motor and installation of the new motor.
Economic Benefit	The simple payback is generally short, often less than two years, if the motor operates continuously; however, if the equipment’s annual hours of operation are minimal, the simple payback period will be extended.
Energy Savings	Savings vary but should be minimally 5 to 10% of the energy used by the lower efficiency motor that was replaced.
Applications and Limitations	None; however, physical characteristics and location of the existing motor must be considered when replacing a motor. For example, the new motor may have to be explosion proof, spark resistant, or have immersion capability (flooding conditions).
Practical Notes	Typically, the best practice is implemented when an existing motor is replaced or needs to undergo major repairs. However, in certain situations, such as high-annual hours of operation, it may be worthwhile to replace a working motor. A program to determine whether it is economically justifiable to replace rather than repair older motors may be beneficial. Note that a premium efficiency motor may require a longer lead time than a standard or high-efficiency motor of the same size. Allow extra time in the project schedule.
Other Benefits	Reduced emissions from the power source directly related to the reduced consumption of electrical power.
Stage of Acceptance	This is a well-known, proven, and accepted technology.

WW 7—Electric Motors: Automate to Monitor and Control

Best Practice	Use automatic controls where possible to monitor and control system functions to optimize energy consumption and treated flows.
Additional Information	WW 6 Electric Motors: Install High Efficiency Motors; WW 8—Supervisory Control and Data Acquisition; WW 9—Electric Motors: Variable Frequency Drives Applications
Primary Area/Process	Automatic controls apply to many aspects of wastewater treatment processes.
Productivity Impact	Minimum impact after installation. In many cases control systems can improve system performance.
Economic Benefit	Payback varies significantly depending on the complexity of the controls added.
Energy Savings	Typically, energy savings result from the ability to match equipment performance to the demands of the system—variable frequency drives are an example.
Applications and Limitations	Control technologies vary from simple applications such as time clocks, which prevent large equipment from operating during peak rate periods, to complex systems like filter backwash monitoring, which control equipment operation based on a number of variables, to automatic monitoring of dissolved oxygen integrated with controlling blower speed.
Practical Notes	Care should be taken in the design and installation of any automatic control system to ensure that the system operates as necessary to meet operational requirements, especially in emergency situations. Make sure that system components needed for emergency situations are available. Look for vendors with process and controls experience to optimize the entire system.
Other Benefits	The use of automatic control systems to monitor a facility may lead to a more in-depth understanding of facility operations.
Stage of Acceptance	Acceptance of automatic controls in the wastewater industry is increasing as simple applications are viewed as “safer” and more complex applications slowly gaining acceptance.

WW 8—Supervisory Control and Data Acquisition (SCADA)

Best Practice	<p>SCADA systems refer to the hardware and software systems that allow treatment plant operators to remotely monitor field instrumentation and equipment—and in some cases make control adjustments to the treatment process. SCADA systems provide the “Human Machine Interface” (HMI) that allow operators to more easily interact with the various electronic controls and field instrumentation used in larger treatment plants. SCADA can improve energy use tracking with routine energy benchmarking:</p> <ul style="list-style-type: none"> • Monitor energy use over time, including comparisons with process variables (e.g., flow, chemical use, lb BOD, lb TSS). • Offset loads and control motor operating times to manage peak demand.
Additional Information	WW 7—Electric Motors: Automate to Monitor and Control
Primary Area/Process	Instrumentation and Controls
Productivity Impact	Minimum impact after installation. In many cases control systems can improve system performance.
Economic Benefit	Payback varies significantly depending on the complexity of the controls added.
Energy Savings	Typically, energy savings result from the ability to match equipment performance to the demands of the system.
Applications and Limitations	The capital investment required to implement a SCADA system can be cost prohibitive for some smaller utilities. Utilities that already utilize SCADA will also incur some additional capital costs for adding energy monitoring capabilities and defining energy benchmarking reports.
Practical Notes	None
Other Benefits	Installation of a SCADA system for central equipment control benefits the whole plant.
Stage of Acceptance	SCADA systems are widely accepted in the wastewater sector.

WW 9—Electric Motors: Variable Frequency Drives Applications

Best Practice	Variable frequency drives (VFDs) match motor output speeds to the load requirement and avoid running at constant full power, thereby saving energy. Equipment must be designed to operate at peak flows. However, these designs are often not energy efficient at average existing flow conditions. Assess variations in facility flows and apply VFDs, particularly where peak demand is significantly higher than the average demand and where the motor can run at partial loads to save energy.
Additional Information	WW 7—Electric Motors: Automate to Monitor and Control
Primary Area/Process	VFDs apply to most processes in wastewater systems. They can replace throttling valves on discharge piping, control the pumping rate of a process pump, control conveyance pressure in force mains, control airflow rates from blowers, and control the speed of oxidation ditch drives.
Productivity Impact	Impact should only be short term with interruption of service during installation, start up, and fine tuning.
Economic Benefit	Now more available and affordable, paybacks for VFDs range from six months to five years. The payback period varies with application depending on size of drive, hours of operation, and variation in load. Large drives, long hours, and high-load variability yield the highest savings.
Energy Savings	Savings vary with application and technology. Many VFDs retrofits have saved 15 to 35%. In some installations, particularly where throttling is used to control flow, savings of 10 to 40% are possible. Applied to a wastewater secondary treatment process, a VFD can save more than 50% of that process's energy use.
Applications and Limitations	Applications for VFDs include controlling pressure, aeration blowers, the pumping rate of raw sewage, and sludge processing.
Practical Notes	Calculations that account for load variation can help justify the cost. The system must be reviewed by an expert before selecting and installing the VFD to ensure system compatibility and cost-effectiveness. VFDs allow operators to fine tune the collection, conveyance, and treatment processes. Matching drives to loads also puts less stress on equipment and reduces maintenance.
Other Benefits	Associated benefits include better control of system flow rate and pressure with minimum energy use. Better control of process flows can lead to reduced chemical usage. An additional benefit is reduced emissions from the power source, which directly relates to the reduced consumption of electrical power.
Stage of Acceptance	Widely accepted and proven in the wastewater sector. New and upgraded wastewater systems are commonly equipped with VFDs for most treatment applications.

WW 10—Electric Motors: Correctly Size Motors

Best Practice	Properly size motors for the specific application. Motors should be sized to run primarily in the 65 to 100% load range. In applications that require oversizing for peak loads, alternative strategies, such as the use of a correctly sized motor backed up with a smaller motor that only operates during peak demand, should be considered.
Additional Information	WW 6—Electric Motors: Install High Efficiency Motors
Primary Area/Process	All electric motors.
Productivity Impact	No productivity impact should result from this best practice, or minimum impact during installation if motors are replaced.
Economic Benefit	Savings vary depending on motor size and application.
Energy Savings	Savings vary depending on motor size and application.
Applications and Limitations	None
Practical Notes	Many motors are oversized for their application, thereby wasting energy. Oversized motors can also result in a lower power factor. Motors that are oversized by more than 50% should be replaced with correctly sized, high-efficiency, or premium-efficiency motors.
Other Benefits	None
Stage of Acceptance	N/A
Resources	<p>The Department of Energy has developed a popular motor selection and management tool: MotorMaster+ software. This free software includes a catalog of more than 25,000 AC motors and features motor inventory management tools, maintenance log tracking, predictive maintenance testing, energy efficiency analysis, savings evaluation capabilities, and environmental reporting. The motor load and efficiency values are automatically determined when measured values are entered into the software. MotorMaster+ can quickly help WRRFs identify inefficient or oversized motors and subsequently calculate the savings that can be achieved with more energy-efficient models.</p> <p>Visit www.energy.gov/node/2553121 to download MotorMaster+.</p>

WW 11–Electric Motors: Properly Maintain Motors

Best Practice	<p>A regular program of preventive maintenance can increase motor efficiency and prolong service life. A typical maintenance program should include:</p> <ul style="list-style-type: none"> • Performance monitoring. Periodic measurements of power consumed in comparison to an initial baseline. • Measurement of resistance provided by winding insulation (Megger testing). • Proper lubrication of motor bearings. • Verification of proper motor coupling alignment, or belt alignment and tension. • Cleaning of cooling vents. • Maintenance of protective circuitry, motor starters, controls, and other switchgear.
Additional Information	None
Primary Area/Process	All electric motors.
Productivity Impact	No impact or minimal impact during motor maintenance.
Economic Benefit	The resources required for motor preventive maintenance should be balanced with cost considerations and expected benefits.
Energy Savings	The energy savings depend on the status of the equipment.
Applications and Limitations	None
Practical Notes	None
Other Benefits	Preventive maintenance benefits all processes in the treatment plant and reduces O&M costs.
Stage of Acceptance	Preventive maintenance of electric motors is well accepted in the wastewater sector.

WW 12–Electric Motors: Improve Power Factor

Best Practice	Improve the power factor of electric motors by minimizing the operation of idling or lightly loaded motors, avoiding operation of equipment above its rated voltage, replacing inefficient motors with energy-efficient motors that operate near their rated capacity, and installing power factor correction capacitors on plant-wide, main electrical distribution or large induction motors.
Additional Information	None
Primary Area/Process	All electric motors.
Productivity Impact	No productivity impact should result from this best practice, or minimum impact during installation if motors are replaced.
Economic Benefit	Savings vary based on motor size and electric utility rates. There is cost savings if a reactive charge is paid on the utility bill for having a poor power factor (e.g., less than 0.95).
Energy Savings	Savings vary but should be minimally 5 to 10% of the energy used by the low-power factor motors.
Applications and Limitations	The installation of either single or banks of power factor capacitors is especially beneficial in facilities with larger motors.
Practical Notes	Periodic monitoring of power efficiency and load factors can provide valuable information, including inefficient motor operation or potential motor failure. A motor's efficiency tends to decrease significantly when operated below 50% of its rated load, and the power factor also tends to drop off at partial load. Replace motors that are significantly oversized with more efficient, properly sized motors.
Other Benefits	Motors and drives require proper and periodical maintenance to ensure they are operating at optimum performance. Periodic monitoring of power efficiency and load factors can provide valuable information, including inefficient motor operation or potential motor failure.
Stage of Acceptance	N/A

WW 13—Pumps: Optimize Pump System Efficiency

Best Practice	Identify the optimum operational conditions for each pump and develop a system analysis. This analysis should include the start-up flows and progress to the design flow capacity, usually a twenty-year projected flow with a peaking factor to identify the range of flow(s) and head conditions required to efficiently meet the conditions and specifications of the system design. Select the pump with the peak-efficiency point relative to the common operation condition of the pump. Consider operating a single pump, multiple pumps, and the use of VFDs.
Additional Information	WW 9—Electric Motors: Variable Frequency Drives Applications; WW 14— Pumps: Reduce Pumping Flow; WW 15—Pumps: Reduce Pumping Head
Primary Area/Process	This technology should be applied to all pumping applications.
Productivity Impact	Optimizing pumping systems can reduce unscheduled downtime, reduce seal replacement costs, and enhance unit process treatment efficiency and effectiveness.
Economic Benefit	The payback period depends on site specifics and whether it is new or retrofit. With a new facility, the payback period should be less than two years; in retrofit conditions, three months up to three years is a typical range.
Energy Savings	The energy saved varies with the installation; 15 to 30% is typical, with up to 70% available in retrofit situations where a service area has not grown as forecasted.
Applications and Limitations	None
Practical Notes	Many computer models can help with the analysis; the model should address both static and dynamic conditions.
Other Benefits	Generally, improved pumping systems provide better treatment system control.
Stage of Acceptance	The technologies used to analyze pumping systems are readily available and their use widely accepted.
Resources	The Department of Energy (DOE) has developed a tool—the Pump System Assessment Tool (PSAT)—that can be used together with the Hydraulic Institute’s Achievable Efficiency Estimate Curves to determine the achievable and optimum efficiencies for the selected pump type as well as correction factors at the specified operating conditions. This method can be used to calculate the energy savings based on the difference between the anticipated energy use of a high-efficiency pump and the baseline energy use associated with the inefficient or oversized pump.

WW 14—Pumps: Reduce Pumping Flow

Best Practice	Reduce the flow in the system. Energy use in a pump is directly proportional to the flow being pumped. Compare design flow with current flow and evaluate if system conditions changed. In some applications (i.e., pumping to a storage tank), it is possible to pump at a lower rate over a longer period of time. Conservation measures such as reduction of infiltration and inflow or leak detection can also reduce the flow that needs to be pumped.
Additional Information	WW 13—Pumps: Optimize Pump System Efficiency
Primary Area/Process	This energy saving practice can be applied to all pumps.
Productivity Impact	None
Economic Benefit	The estimated payback varies with improvements and comparisons with a base alternative. While load shifting and demand flattening (pump at a lower rate over a longer period of time) do not necessarily result in reduced energy use, they do result in reduced electricity costs.
Energy Savings	The potential savings vary with the type of modifications being considered.
Applications and Limitations	All pumping systems.
Practical Notes	A detailed evaluation should be completed to identify the potential energy savings for each installation.
Other Benefits	None
Stage of Acceptance	N/A

WW 15—Pumps: Reduce Pumping Head

Best Practice	Reduce the total system head losses, which include static head and friction head losses (due to velocity, bends, fittings, valves, pipe length, diameter, and roughness). Energy use in a pump is directly proportional to the head. Plot system curve at the time of installation and compare output on the certified curve. Calculate efficiency and save for future reference. Plot system curve on a yearly basis; examine and re-plot at shorter period if problems develop. Avoid using throttling valves to control the flow rate. Run higher wet well level on suction side (if practical). Increase pipeline size and/or decrease pipe roughness.
Additional Information	WW 13—Pumps: Optimize Pump System Efficiency, and WW 16—Pumps: Avoid Pump Discharge Throttling
Primary Area/Process	This energy saving practice can be applied to all pumps.
Productivity Impact	None
Economic Benefit	The estimated payback varies with improvements and comparisons with a base alternative.
Energy Savings	The potential savings vary with the type of modifications being considered.
Applications and Limitations	All pumping systems.
Practical Notes	A detailed evaluation should be completed to identify the potential energy savings for each installation.
Other Benefits	Reduced pump wear, longer service life, and less maintenance.
Stage of Acceptance	Reducing the head on pumping systems is readily accepted in the wastewater sector.

WW 16—Pumps: Avoid Pump Discharge Throttling

Best Practice	Modify operation of system to eliminate the use of throttling valves to control the flow rate from pumps. Consider energy-efficient, variable-speed drive technologies, such as variable frequency drives (VFDs).
Additional Information	WW 9—Electric Motors: Variable Frequency Drives Applications
Primary Area/Process	This technology is most often applied to booster pump discharges.
Productivity Impact	None
Economic Benefit	Payback varies by application and may be less than one year if pump run time is high and valve closure is significant. However, the savings can be as low as 15% of total energy consumption if the pump has low hours of operation and the throttling valve is minimally closed.
Energy Savings	Energy savings can exceed 50% of pumping energy in some cases. Actual savings depend on the amount of closure of the throttling valve.
Applications and Limitations	All locations currently using valves to control flows.
Practical Notes	A detailed evaluation should be completed to identify the potential energy savings for each installation considering a variable frequency drive.
Other Benefits	Ability to quickly and easily adjust flow as changes occur in the distribution system. Reduced pump wear, longer service life, and less maintenance.
Stage of Acceptance	The industry accepts the use of VFDs to replace throttling valves in order to save large amounts of energy.

WW 17—Optimize Grit Removal System

Best Practice	<p>There are different styles of grit removal systems that consume different levels of energy. For vortex design grit basins, operate grit pumps on cycles to prevent buildup of grit without operating continuously. Connect grit washer and conveyor drives to operate only when pumps are operated and for some reasonable period of time after the pumps are shut off.</p> <p>For aerated grit chambers, perform tests to determine the optimal blower output; too little air results in organic material settling at the bottom of the tank, which causes odors, and too much air prevents the effective removal of grit.</p>
Additional Information	WW 5—Idle or Turn off Equipment; WW 6—Electric Motors: Install High Efficiency Motors; WW 7—Electric Motors: Automate to Monitor and Control
Primary Area/Process	Primary application for this practice is grit removal systems.
Productivity Impact	If grit is not effectively removed at the front of the plant, it can impact equipment operation. Grit can accumulate in anaerobic digesters, reducing the effective volume of sludge being digested and therefore reducing the potential for gas generation.
Economic Benefit	Payback varies with the modifications required.
Energy Savings	Energy savings vary depending on the specific site conditions.
Applications and Limitations	All grit removal systems.
Practical Notes	None
Other Benefits	Optimization of the grit removal system benefits maintenance of downstream equipment and sludge processing, treatment, and disposal.
Stage of Acceptance	Optimization is generally understood and widely accepted.

WW 18—Chemically Enhanced Primary Settling

Best Practice	Add chemicals to primary settling tanks to enhance sedimentation. Chemicals are metal salts (e.g., ferric chloride, aluminum sulfate) commonly used for coagulation and flocculation. Mixing and chemical addition equipment is required. Chemically Enhanced Primary Settling (CEPS) results in increased organics and solids removal, therefore reducing the energy requirements of the secondary processes.
Additional Information	WW 19—Optimize Aeration System; WW 21—Variable Blower Airflow Rate; WW 22—Dissolved Oxygen Control; WW 34—Optimize Anaerobic Digester Performance
Primary Area/Process	This practice applies to primary settling.
Productivity Impact	Interruption in production should occur only during installation. Increased primary sludge production should be expected. BOD removal efficiency of CEPS can be as high as 55%, compared to 30 to 35% of traditional primary settling.
Economic Benefit	For facilities treating sludge in anaerobic digestion and using digester gas in CHP systems, generation of electricity will increase.
Energy Savings	The potential energy savings vary by application but can be as high as 30%.
Applications and Limitations	CEPT is easily implemented over existing infrastructure.
Practical Notes	None
Other Benefits	CEPT provides the opportunity for either reducing the size of secondary treatment or increasing the capacity of existing activated sludge tanks.
Stage of Acceptance	This process is not widely used, but it is gaining industry interest.

WW 19—Optimize Aeration System

Best Practice	Determine whether the aeration system is operating as efficiently as possible for the required level of treatment. Assess present loading conditions and system performance through a comparison of kilowatt-hours per million gallons (kWh/mg) and other key performance indicators with those of similar facilities. Consider the potential benefits and costs of improvements such as fine-bubble aeration, dissolved oxygen control, and variable airflow rate blowers.
Additional Information	WW 1—Operational Flexibility; WW 20—Fine Bubble Aeration; WW 21—Variable Blower Airflow Rate; WW 22—Dissolved Oxygen Control
Primary Area/Process	Secondary treatment process activated sludge, aerobic digestion, aerated channels and post-aeration systems are the principal treatment processes where this energy saving practice can be implemented.
Productivity Impact	Modified aeration systems have also resulted in savings for other treatment unit processes. Savings have materialized in biosolids processing, particularly in reducing the polymer dosage for biosolids thickening and dewatering. Treatment capabilities have been increased at most facilities.
Economic Benefit	The payback period is generally three to seven years for retrofits and about one year for new construction.
Energy Savings	Savings of 30 to 70% of total aeration system energy consumption are typical.
Applications and Limitations	All aerated treatment systems.
Practical Notes	The best practice should be implemented at all facilities unless a reason to avoid it is overwhelming.
Other Benefits	Improvement in other unit treatment processes on site and reduced maintenance at some installations.
Stage of Acceptance	Fine-bubble aeration methods are widely accepted, as are dissolved oxygen control systems and various methods of controlling the flow rate of air to the treatment process.

WW 20—Fine-Bubble Aeration

Best Practice	Assess the feasibility of implementing fine-bubble aeration at activated sludge treatment facilities. This practice provides energy efficient treatment of wastewater. It can be installed in new or existing systems. The technology usually improves operations and increases the organic treatment capability of a wastewater treatment facility. For optimum performance, combine this practice with dissolved oxygen monitoring and control as well as a variable capacity blower. Plan for periodic diffuser cleaning (in-place gas cleaning system or scheduled drain and manual cleaning) as diffuser fouling influences system pressure and oxygen transfer efficiency.
Additional Information	WW 19—Optimize Aeration System; WW 21—Variable Blower Airflow Rate; WW 22—Dissolved Oxygen Control
Primary Area/Process	Primary application for this practice is on aeration tanks and aerobic digesters.
Productivity Impact	A minor impact on production during installation.
Economic Benefit	Economic benefits vary from new facilities to retrofit applications. A new system may pay back in as little as one year. Payback on a retrofit varies depending on the inefficiency of the existing system and the amount of new equipment required.
Energy Savings	Energy savings range from 20 to 75% of the aeration or aerobic digestion system's energy consumption.
Applications and Limitations	This practice applies to all aeration systems. A limit exists for aerobic digestion—if the system operates at a solids concentration of 2.5% or greater, further review must be done.
Practical Notes	Fine-bubble technologies have applications for all sizes of wastewater treatment facilities. The percentage range of energy savings is similar regardless of facility size.
Other Benefits	Most sites that have implemented this practice report improved biosolids management, reduced polymer use, better clarification, and better overall effluent.
Stage of Acceptance	This technology has gained a high level of acceptance within the industry.

WW 21—Variable Blower Airflow Rate

Best Practice	This best practice requires that aeration system and aerobic digester blowers have variable air supply rate capability, such as single stage centrifugal blowers with VFD, positive displacement blowers with VFD, inlet guide-controlled, multi-stage centrifugal blowers, and turbo blowers with built-in variable speed. The range of variability should respond to the specific requirements a site needs to precisely match system demands. The blower system should be able to supply the minimum airflow required to meet existing low-load conditions or mixing and to meet the high loads of design conditions. Avoid airflow discharge throttling.
Additional Information	WW 19—Optimize Aeration System; WW 20—Fine-Bubble Aeration; WW 22—Dissolved Oxygen Control; WW 9—Electric Motors: Variable Frequency Drives Applications
Primary Area/Process	The practice applies to all aeration systems, including activated sludge aeration tanks and aerobic digestion systems.
Productivity Impact	Interruption in production should only occur during installation.
Economic Benefit	Payback is usually under three years.
Energy Savings	Energy savings depend on site conditions and which parameter, mixing or organic loading, dictates the lesser amount of airflow. Savings range from 15 to 50% of the energy consumed by this process.
Applications and Limitations	The practice can be applied wherever blowers are installed.
Practical Notes	Variable airflow rate blowers should be integrated with fine-bubble aeration and dissolved oxygen monitoring and control for optimum energy efficiency. Also consider the potential advantages of replacing two blowers and staging loadings with three, four, or five smaller units that can both meet current and future demands.
Other Benefits	When teamed with fine-bubble diffusers and dissolved oxygen (DO) control technologies, effluent quality and biosolids processing are usually improved.
Stage of Acceptance	Technologies for varying airflow rates are well received. Variable speed positive displacement blower arrangements and variable capacity centrifugal blowers are becoming more available and well known.
Resources	The Department of Energy (DOE) has developed a tool—the Fan System Assessment Tool (FSAT)—that can be used to determine the achievable and optimum efficiencies for the selected blower type at the specified operating conditions. This tool can be used to calculate the energy savings based on the difference between the anticipated energy use of a high-efficiency blower and the baseline energy use.

WW 22—Dissolved Oxygen Control

Best Practice	Consider dissolved oxygen monitoring and control technology which maintains the dissolved oxygen (DO) level of the aeration tank(s) at a preset control point by varying the airflow rate to the aeration system.
Additional Information	WW 1—Operational Flexibility; WW 19—Optimize Aeration System; WW 20—Fine-Bubble Aeration; WW 21—Variable Blower Airflow Rate
Primary Area/Process	The primary applications are (1) aeration tanks at activated sludge facilities; (2) aerobic digestion systems; and (3) post-aeration systems.
Productivity Impact	Installation of most systems can be accomplished without interfering with normal operation.
Economic Benefit	Paybacks from improved monitoring and controls using DO control are two to three years.
Energy Savings	Savings vary depending on the efficiency of the present system. Generally, energy savings for the aeration system are in the 20 to 50% range.
Applications and Limitations	Limitations vary with characteristics of the waste being treated. If the waste has characteristics that would easily foul the DO probe, then the system would not be readily applicable.
Practical Notes	This control should be employed at post-aeration systems and wherever activated sludge is utilized as the secondary treatment process. Variable flow may be established with variable frequency drives (VFDs).
Other Benefits	Waste biosolids from a DO controlled system have reportedly better dewatering characteristics. Also, a DO controlled system usually has fewer problems treating a fluctuating influent load.
Stage of Acceptance	DO control is a well-accepted control methodology. The primary factor affecting acceptance is the reliability and associated maintenance related to DO probes.

WW 23–Filtration: Sequence Backwash Cycles

Best Practice	A filtration system can have high-energy costs, and the highest energy users for filtration systems are typically the backwash pumps. Consider sequencing of backwash cycles and off-peak backwash times to reduce the electric demand. In some applications, it is possible to pump at a lower rate over a longer time to a water storage tank located at a higher elevation, and backwash by gravity.
Additional Information	None
Primary Area/Process	Granular or membrane filtration systems are applied in tertiary treatment of wastewater systems.
Productivity Impact	Productivity should not be impacted by sequencing of backwash cycles.
Economic Benefit	Savings result from a lower demand due to the staggered operation of backwash pumps.
Energy Savings	Energy consumption savings (kilowatt-hours) are generally minor. Savings result from reduced demand for peak power.
Applications and Limitations	When operators have to be present, backwashing during off-peak time can affect the staffing needs or labor costs.
Practical Notes	None
Other Benefits	Sequencing of backwash cycles gives a more stable and constant operation of filter units.
Stage of Acceptance	Sequencing of backwash cycles is a well-accepted practice.

WW 24–Post-Aeration: Cascade Aeration

Best Practice	Consider the installation of a cascade aeration system for post-aeration applications. If the topography is favorable, this technology provides re-aeration of the effluent by increasing the water turbulence over the steps, with no need for electricity.
Additional Information	None
Primary Area/Process	Post-aeration of wastewater treatment plants effluent.
Productivity Impact	Installation can be accomplished without interfering with normal operation.
Economic Benefit	Payback varies depending on the existing post-aeration system used.
Energy Savings	If cascade aeration is used to replace an existing post-aeration system with a subsurface diffuser system and blowers, 100% of the electricity used is going to be saved.
Applications and Limitations	The application is site specific. At least 10 to 15 feet of head are needed between the plant effluent point and the final discharge, due to the low oxygen transfer rate and the temperature dependency of oxygen transfer.
Practical Notes	None
Other Benefits	N/A
Stage of Acceptance	Cascade aeration for effluent re-aeration is a well-accepted method.

WW 25—Ultraviolet (UV) Disinfection Options

Best Practice	Consider low-pressure or low-pressure, high-output UV systems, which are more energy efficient than medium-pressure UV systems. Some newer systems in between low-pressure, high-output and medium pressure combine low-lamp count, low-power consumption and can be dimmed from 100 to 30% power. Install lamp intensity adjustment (dose pacing) based on flow rate or water quality, particularly UV transmittance (UVT), for low-pressure, high-output, and medium-pressure systems. Regularly clean lamps, as lamp sleeve fouling affects equipment performance.
Additional Information	WW 26—UV Disinfection: Install Dose Pacing
Primary Area/Process	UV disinfection options apply to wastewater facilities.
Productivity Impact	Minor impact on productivity during the installation of any improvements.
Economic Benefit	Paybacks vary depending on the type of UV system in use and the extent of renovations required.
Energy Savings	Low-pressure, high-output UV lamps use about 50% less energy than medium-pressure lamps. Typical energy requirements for low-pressure, high-output systems range from 3.2 to 4.8 kWh/mgd, while medium-pressure systems use about 6.8 kWh/mgd. Sleeve cleaning alone can save 10% of UV system energy costs.
Applications and Limitations	Energy savings may be lower for systems that operate seasonally, due to limited annual hours of operation.
Practical Notes	Medium-pressure lamps convert a lower percentage of the power they consume into useful light, compared with low-pressure, high-output lamps. Additionally, medium-pressure lamps offer much lower turndown capabilities. Consequently, a medium-pressure system may use significantly more energy, despite having fewer lamps. Low-pressure UV lamps are typically used for flows not exceeding 38 mgd. For higher wastewater flows, or when space is limited, lamps with higher UV output per watt or medium-pressure UV lamps are required. Including an automatic cleaning (wiping) system ensures that the quartz sleeves stay clean and that the maximum amount of UV can be transferred.
Other Benefits	Installation of an ultraviolet (UV) system usually replaces a chlorination system, thereby eliminating the need to store chlorine on site, as either a hazardous gas or corrosive liquid.
Stage of Acceptance	Many varieties and configurations of UV disinfection systems are accepted and in use throughout the wastewater sector.

WW 26—UV Disinfection: Install Dose Pacing

Best Practice	Consider installing a dose pacing system on an existing UV disinfection system provided with turndown capability. Some lamps can be dimmed from 100 to 30% power. UV dose can be varied in proportion to flow, assuming a constant UVT, or more advance controls can vary the dose based on both flow and UVT.
Additional Information	WW 25—Ultraviolet (UV) Disinfection Options
Primary Area/Process	This practice applies to UV disinfection.
Productivity Impact	Minor impact on productivity during the installation of any improvements.
Economic Benefit	Paybacks vary depending on the type of UV system in use and the extent of renovations required.
Energy Savings	Energy savings from UV pacing result when the number of lamps “on” and lamp output are paced based on flow and transmittance.
Applications and Limitations	Energy savings may be lower for systems that operate seasonally, due to limited annual hours of operation.
Practical Notes	Controlling UV disinfection with a flow or dose paced strategy can result in significant energy and cost savings.
Other Benefits	Installation of a UVT sensor continuously monitoring the transmittance helps to adjust the UV dose when systems are designed for the worst-case measured UVT.
Stage of Acceptance	Adjusting UV power based on actual conditions is a well-accepted practice.

WW 27–Sludge: Improve Solids Capture in DAF System

Best Practice	Optimize the air-to-solids ratio in a Dissolved Air Flotation (DAF) system by adjusting the supply air and/or feeding the highest possible solids content. Additionally, energy use can be reduced by operating the DAF thickener continuously and adding polymers to the sludge.
Additional Information	None
Primary Area/Process	DAF thickeners are used in sludge dewatering and thickening processes.
Productivity Impact	None
Economic Benefit	DAF thickeners have high-operating costs because they require a significant amount of energy for air pressurization. Payback varies depending on the degree of optimization.
Energy Savings	Energy use can be reduced by improving solids capture. Savings depend on the application.
Applications and Limitations	Continuous operation of the DAF thickener and addition of polymers can increase O&M or labor costs.
Practical Notes	None
Other Benefits	Improved solids capture benefits the other sludge treatment processes downstream of sludge thickening.
Stage of Acceptance	Widely accepted by the industry.

WW 28—Sludge: Replace Centrifuge with Screw Press

Best Practice	Replace the sludge dewatering centrifuge with a screw press for energy savings.
Additional Information	WW 29—Sludge: Replace Centrifuge with Gravity Belt Thickener
Primary Area/Process	Sludge dewatering and thickening.
Productivity Impact	Minimal impact during installation and replacement of equipment.
Economic Benefit	Payback depends on the size of the application.
Energy Savings	Potentially high-energy savings can be obtained by this best practice.
Applications and Limitations	A centrifuge is a relatively large energy consumer. Replacing a centrifuge with a screw press saves energy, due to the simple, slow-moving mechanical dewatering equipment that continuously dewateres the sludge by gravity drainage. The primary disadvantages with a screw press include potential for odor problems and larger space requirements. Solids thickening impacts energy use in sludge digestion, dewatering, and disposal. The screw press produces sludge with a lower solids concentration than a centrifuge, therefore the full life cycle of solids operation must be considered for cost-effective operation.
Practical Notes	When designing sludge dewatering equipment, it is more efficient to fit the minimum size equipment for the dewatering requirements and have the plant running continuously, than to install oversized equipment that runs for just a few hours per day. This can save energy in two ways. First, any sludge that is held in liquid form before dewatering will need to be agitated or aerated, both of which require unnecessary power. Second, smaller dewatering equipment will require smaller motors.
Other Benefits	In addition to lower energy consumption, the screw press also has lower operation and maintenance costs than the centrifuge. Furthermore, the screw press can produce Class A biosolids if modified (by adding heat).
Stage of Acceptance	Screw presses are widely accepted for sludge dewatering.

WW 29—Sludge: Replace Centrifuge with Gravity Belt Thickener

Best Practice	Replace centrifuge with gravity belt thickener for improved sludge thickening.
Additional Information	WW 28—Sludge: Replace Centrifuge with Screw Press
Primary Area/Process	Sludge dewatering and thickening.
Productivity Impact	Minimal impact during installation and replacement of equipment.
Economic Benefit	Payback depends on the size of the application.
Energy Savings	Potentially high-energy savings can be obtained by applying this best practice.
Applications and Limitations	A gravity belt thickener consists of a gravity belt driven by a motor. As the sludge makes its way down the horizontally-moving belt, water drains through the porous belt. The solids are continuously turned to enhance the drainage process. Solids thickening impacts energy use in sludge digestion, dewatering, and disposal. The gravity belt thickener produces sludge with a lower solids concentration than a centrifuge, therefore the full life cycle of solids operation must be considered for cost-effective operation.
Practical Notes	None
Other Benefits	Other advantages associated with gravity belt thickeners include small space requirements and ease of automation and control.
Stage of Acceptance	Gravity belt thickeners are widely accepted for sludge thickening.

WW 30—Biosolids Digestion Options

Best Practice	<p>When planning new facilities or expansion, assess the energy and production impacts of various biosolids process options. Standard aerobic digestion of biosolids is energy intensive compared to fine-bubble diffusers with dissolved oxygen control and a variable air-flow rate blower. Some locations currently turn off the airflow to the digester over extended periods of time to further reduce energy costs.</p> <p>Anaerobic digestion requires detailed assessment. While the capital cost of an anaerobic system is considerably greater than for an aerobic system, an anaerobic system consumes less energy and can produce biogas for energy production to help offset capital costs. Both types of system should be considered.</p>
Additional Information	WW 31—Aerobic Digestion Options; WW 34—Optimize Anaerobic Digester Performance
Primary Area/Process	This practice applies to biosolids treatment and management.
Productivity Impact	The energy impact of recycling supernatant by each process should be assessed.
Economic Benefit	Payback varies considerably from site to site and should be determined on a system specific basis.
Energy Savings	Both aerobic and anaerobic systems should be considered to determine the most energy efficient option.
Applications and Limitations	Each facility must identify the class of biosolids it wants to produce which will affect the type of biosolids treatment selected.
Practical Notes	Operators should include all site-specific parameters for the assessment, particularly the amount of energy both consumed and produced by each process.
Other Benefits	Each type of treatment process affects the characteristics of the solids product, which in turn affects production rates and thickening and dewatering capabilities.
Stage of Acceptance	Both aerobic and anaerobic biosolids digestion are readily available and widely accepted treatment processes.

WW 31—Aerobic Digestion Options

Best Practice	Assess your aerobic digester operation to determine if a smaller blower and/or using fine-bubble diffusers and equipment with adjustable airflow rates would provide better control of airflow. Many facilities operate aerobic digesters with surface aerators or coarse-bubble diffusers with limited ability to modify or control airflow delivered to the process. First, consider fine-bubble diffusers, which allow for variable airflow rates in digester applications. Second, choose equipment and/or controls with adjustable airflow rates. Often, air for the digestion process is bled from the secondary treatment process activated sludge blowers, allowing little or no control over the airflow delivered.
Additional Information	WW 19—Optimize Aeration System; WW 20—Fine-Bubble Aeration; WW 21—Variable Blower Airflow Rate; WW 22—Dissolved Oxygen Control; WW 30—Biosolids Digestion Options; WW 32—Biosolids Mixing Options in Aerobic Digesters
Primary Area/Process	Applies to biosolids treatment and management.
Productivity Impact	Conversion to fine-bubble diffuser technology may improve reduction of volatile solids.
Economic Benefit	Payback varies with the modifications required.
Energy Savings	Application of fine-bubble diffusers in an aerobic digestion system can reduce energy consumption for the process by 20 to 50%.
Applications and Limitations	The key limitation is the final concentration of total suspended solids (TSS) in the digester. Operators may want to be involved in control of the concentration of TSS to maintain applicability of fine-bubble. Mixing can also be a limitation.
Practical Notes	The best practice is applicable to most systems but typically requires that the diffusers and blowers be replaced. Some piping modifications may also be required.
Other Benefits	Fine-bubble aeration reportedly improves biosolids dewatering, reduces polymer demand when the digested biosolids are dewatered or thickened, results in less pin floc in the biosolids processing, enhances reduction of volatile solids, improves decanting from the digester and reduces the volume of biosolids to be disposed.
Stage of Acceptance	The technology is readily available and widely accepted except in situations where the solids concentration within the digester exceeds 2.5% of total solids.

WW 32—Biosolids Mixing Options in Aerobic Digesters

Best Practice	Biosolids mixing is an energy intensive task that should be addressed in aerobic digestion. Mixing is generally provided by aeration, mechanical mixing, pumping, or a combination of these methods. Aeration of the biosolids mass is required to destroy volatile solids and control odor. However, aeration may not be the most energy-efficient way to provide complete mixing in a digester, especially if constant aeration is not required. Evaluate the energy costs of available options to identify the best technology for the site. A combination of mixing methods that permit the system to be completely turned off periodically may be most practical.
Additional Information	WW 31—Aerobic Digestion Options
Primary Area/Process	This practice applies to all aerobic digestion systems.
Productivity Impact	No impact on productivity. A disruption should only occur during installation and start up.
Economic Benefit	The payback period for a retrofit condition typically takes one to three years. A new installation payback may only take one year.
Energy Savings	The potential energy savings vary by application but can be as high as 50%.
Applications and Limitations	The limiting factor is the solids concentration in the aerobic digester.
Practical Notes	The solids concentration of the digester contents should be controlled to an approximate maximum suspended solids concentration of 2.5%.
Other Benefits	Improved volatile solids reduction.
Stage of Acceptance	Mixing technologies, including a combination of a mixing regime and an aeration methodology, are accepted by the wastewater industry.

WW 33—Biosolids Mixing Options in Anaerobic Digesters

Best Practice	The contents of an anaerobic digester must be mixed for proper operation, the destruction of volatile suspended solids, and the production of biogas. Mixing types are generally classified as gas, hydraulic sludge, and mechanical. Large bubble compressed biogas fired through nozzles distributed across the digester floor is an example of energy-efficient gas mixing. Pumps with VFDs that deliver sludge to the digester through strategically placed nozzles and used in on/off cycles can provide energy savings in hydraulic mixing systems. Vertical linear mixers use less power than traditional mechanical mixers while obtaining similar homogeneous mixing. Evaluate the energy costs of available options and site constraints to identify the best technology for the site.
Additional Information	WW 34—Optimize Anaerobic Digester Performance; R1—Generate Energy from Biosolids
Primary Area/Process	This practice applies to the anaerobic digestion of biosolids.
Productivity Impact	Disruption in production should only occur during installation and while the biological environment evolves to make the anaerobic system function.
Economic Benefit	Payback depends on whether the system is new construction or a retrofit of an existing system. Payback for a retrofitted system takes longer.
Energy Savings	Energy savings vary substantially depending on the specific site conditions.
Applications and Limitations	Mixing should be employed by all anaerobic digestion systems to maximize volatile solids destruction and biogas production.
Practical Notes	The various methods of mixing must be evaluated to identify the best option. It is important to assess the production and beneficial use of biogas.
Other Benefit	Maximizing the production of biogas may provide a lucrative renewable energy opportunity.
Stage of Acceptance	Various mixing technologies are widely accepted throughout the industry.

WW 34—Optimize Anaerobic Digester Performance

Best Practice	<p>Optimize anaerobic digester performance and enhance biogas production. Primary ways of optimizing anaerobic digestion are as follows:</p> <ul style="list-style-type: none"> • Optimizing effective volume. Drain and clean digesters to remove grit that may have accumulated at the bottom of the tanks. • Recuperative loop or Torpey Process. Increase sludge residence time (SRT) by mixing a portion of digested sludge with feedstock sludge ahead of the thickening step and returning to the digesters, in a similar way as the activated sludge is returned to the aeration basin after secondary clarification. • Optimizing process temperature. Make sure operating temperature is kept constant (a 1 degree °C change per day can affect performance) and well mixed—with a steady feed of homogeneous sludge. • Optimizing process temperature. Changing the digester operating temperature from mesophilic (85–105 °F) to thermophilic (125–140 °F) increases the rate of destruction for volatile solids in the sludge. Two-phased anaerobic digestion and temperature-phased digestion have shown potential benefits in volatile solids reduction and biogas enhancement. Thermophilic digestion can also be considered to produce Class A biosolids. • Sludge (WAS) pre-treatment. The hydrolysis step is often the limiting factor in anaerobic digestion. Hydrolysis can be improved by pre-treatment to enhance the ability of microorganisms to digest the sludge. There are various pre-treatment methods available, including chemical, physical, and biological methods. Three of the most promising methods include thermal and ultrasonic treatments and enzyme dosing.
Additional Information	R1—Generate Energy from Biosolids; WW 330—Biosolids Mixing Options in Anaerobic Digesters
Primary Area/Process	Anaerobic sludge digestion.
Productivity Impact	Minimal impact during installation of equipment.
Economic Benefit	Optimized anaerobic digesters produce more biogas, which is beneficial in WRRFs that generate heat and power. The economic benefit of increased biogas production may be reduced by the cost of sludge pre-treatment equipment, most of which is proprietary.
Energy Savings	Energy savings are proportional to the additional production of biogas for power and/or heat generation.
Applications and Limitations	None
Practical Notes	Optimization of the anaerobic digester performance benefits sludge quality for downstream sludge processing, treatment, and disposal.
Other Benefits	N/A
Stage of Acceptance	Some of these optimization techniques are not widely used but are gaining industry interest.

WW 35—Cover Basins for Heat Reduction

Best Practice	In northern climates, basins are often covered to prevent the contents from freezing. This practice reduces, or possibly eliminates, the energy used to thaw equipment or tanks. For tanks located in rooms where frequent air changes are required, basins can be covered to reduce the requisite volume of air. Recovery of waste heat from the exhaust air or blending with outside air can provide additional savings.
Additional Information	None
Primary Area/Process	This practice may be applied to any open tank treatment process including grit removal, comminution, clarification, aeration, gravity thickeners, aerobic digesters, biosolids holding tanks, and disinfection tanks.
Productivity Impact	Installation of covers would interrupt the use of a tank for a limited time during installation.
Economic Benefit	Payback depends on the number of tanks and the fuel used to thaw any frozen items or on the size of the room where tanks are located. The payback period increases with the amount of equipment needed to implement this practice.
Energy Savings	Savings vary depending on the number of open tanks on site and the total storage volume.
Applications and Limitations	Limitations are related to weather conditions—the colder the climate, the better the application.
Practical Notes	Many enclosure materials are available. Information on these materials can be found on manufacturers' websites.
Other Benefits	Reduced odor and aerosol control are auxiliary benefits from covering a structure. Operations improve as a result of maintaining a more consistent temperature.
Stage of Acceptance	Covering open tanks is a widely accepted practice throughout the industry. However, in most instances the tanks are covered for odor or aerosol control. Covering systems as an energy efficiency measure is gaining acceptance.

WW 36—Recover Excess Heat from Wastewater

Best Practice	Recover excess heat from wastewater prior to its treatment and/or discharge to use at or near the water resource recovery facility. Some industrial wastewater systems have a large volume of low-grade heat available in their wastewater (typically able to provide 20°F to 25°F).
Additional Information	None
Primary Area/Process	Wastewater stream processes where heat recovery is feasible, especially where the demand for additional heat is nearby.
Productivity Impact	There are possible minor disruptions during installation of piping and equipment and during start-up.
Economic Benefit	The payback period is typically short (less than two years) but this varies and is a direct function of the distance between the heat source and where it is used.
Energy Savings	The total value of heat energy available varies depending on site characteristics. The heat value available can be in the millions of therms per year.
Applications and Limitations	Use of low-grade heat is a challenge. In many applications it can be used to preheat influent river or well water to a tepid temperature (preheating influent raw water). Even if the available heat is insufficient to completely heat process streams, partial heating can reduce heating fuel costs and yield significant benefits. The distance between the heat recovery source and the application determines the economic feasibility.
Practical Notes	In order to optimize the use of waste heat, assess the locations within the facility where the waste heat could be captured at higher temperatures before mixing it with other wastewater streams to maximize the overall temperature differential and heat transfer potential.
Other Benefits	Warming raw water usually decreases the amount of pretreatment chemicals required for conditioning.
Stage of Acceptance	This process is accepted, but often not utilized, because the heat source is low grade. Operators often mistakenly perceive that partial heating, as opposed to complete heating, is insufficient and not worth it.

WW 37—Reduce Fresh Water Consumption/Final Effluent Recycling

Best Practice	Reducing the consumption of potable water through the use of final effluent (FE) in process applications or washdown of tanks may save energy by limiting the volume of water treated and/or pumped. The FE system should include a pressure tank and pump control system, where appropriate, and direct pumping where consistent high pressure is required (belt press). Additional applications are possible with an inline filter prior to each application.
Additional Information	None
Primary Area/Process	Typical applications are in the recycle system for tank washdown, gravity belt thickener belt wash water, belt press belt wash water, cooling water for a compressor, etc.
Productivity Impact	No impacts are expected, other than minor interruptions during the installation of any required equipment.
Economic Benefit	Payback periods for this best practice are typically two to three years and vary with the volume of potable water currently used.
Energy Savings	Savings may reach 50% of the total system energy if the existing system does not utilize a pressure tank system to regulate supply.
Applications and Limitations	Application is limited by the quality of effluent available for recycling.
Practical Notes	The best practice is usually implemented when the final effluent quality is sufficiently high so that its use does not hamper the function of pumps, hoses, and nozzles used in its distribution. The practice is also cost effective when large volumes of wash water are required, such as for biosolids processing or facility washdown.
Other Benefits	Other potential benefits associated with this measure include reducing well-water consumption, reducing operation of booster pumps, where applicable, and possibly eliminating the need for two water distribution systems throughout the facility.
Stage of Acceptance	Reducing the volume of potable water used in the wastewater treatment process is widely accepted throughout the industry.

3.4 Building Systems Energy Management Best Practices

B1—Annual Compressed Air Leakage Survey

Best Practice	Leaks can be a significant source of wasted energy in compressed air systems, sometimes wasting 20 to 30% of a compressor's output. A typical plant that has not been well maintained will likely have a leak rate equal to 20% of total compressed air production capacity. Conversely, proactive leak detection and repair can reduce leaks to less than 10% of compressor output. In addition to wasting energy, leaks can also contribute to other operating inefficiencies. Leaks cause a drop in the system's pressure, which can make air tools function less efficiently, adversely affecting production. Additionally, air leaks shorten the life of almost all system equipment (including the compressor package itself) by forcing the air compressor to run longer and cycle more, especially during off-work periods. Increased run time can also lead to additional maintenance requirements and increased unscheduled downtime. Air leaks also can result in owners adding unnecessary compressor capacity.
Additional Information	B 2—Optimize Compressed Air System Pressure; B 3—Install VFD Control on Air Compressors
Primary Area/Process	Compressed air systems are often found in machine shops where they are used for various maintenance functions. They are also used to operate hydraulic drives and pumps and, in some situations, pneumatic controls.
Productivity Impact	Better distribution of compressed air at a constant pressure, less cycling of compressors, and more reliable operation.
Economic Benefit	Payback is typically very short and is a function of the compressor size and compressed air distribution system size. Reducing leaks also increases equipment longevity.
Energy Savings	Energy savings is a function of the target pressure and quantity of air leaks.
Applications and Limitations	None
Practical Notes	None
Other Benefits	None
Stage of Acceptance	Widely accepted by the industry.

B2—Optimize Compressed Air System Pressure

Best Practice	<p>Many air compressors operate with a full-load discharge pressure of 100 pounds per square inch gauge (psig) and an unloading discharge pressure of 110 psig or higher. Many types of process controls, machinery, and tools can operate efficiently with an air supply at the point-of-use at 80 psig or lower. If the air compressor discharge pressure is reduced, significant savings can be achieved. Check with the compressor manufacturer for performance specifications at different discharge pressures.</p> <p>Reducing system pressure also can have a cascading effect in improving overall system performance by reducing leakage rates and helping with capacity and other problems. Reduced pressure also reduces stress on components and operating equipment. However, a reduced system operating pressure may require modifications to other components, including pressure regulators, filters, and the size and location of compressed air storage. The overall system needs to be evaluated to determine if reducing air pressure will cause the pressure at remote points-of-use to fall below minimum operating requirements. These problems can be avoided with careful matching of system components, controls, and compressed air storage capacity and location.</p>
Additional Information	B 1—Annual Compressed Air Leakage Survey; B 3—Install VFD Control on Air Compressors
Primary Area/Process	Compressed air systems are often found in machine shops where they are used for various maintenance functions. They are also used to operate hydraulic drives and pumps and, in some instances, pneumatic controls.
Productivity Impact	Better distribution of compressed air at a lower pressure in-line with end-use requirements. Less cycling of compressors and a more reliable system with reduced leakage rates.
Economic Benefit	Payback is typically very short and is a function of the compressor size and compressed air distribution system size.
Energy Savings	Typically, for every 2 pounds per square inch (psi) of pressure reduction, energy savings equal to 1% of compressor energy use (operating in the 100 psig range) can be achieved.
Applications and Limitations	None
Practical Notes	None
Other Benefits	Improved consistency of performance of pneumatic equipment.
Stage of Acceptance	Widely accepted by the industry.

B 3—Install VFD Control on Air Compressors

Best Practice	Compressors produce a wide range of airflow rates between 80 to 140 psi. Many of these air compressors are rotary screw-type and are typically operated using inlet modulation with an unloading mode to provide varied airflow rates. In this control scheme, the air compressor produces compressed air until a desired discharge pressure is reached, at which point it begins modulating and then unloads. When it unloads, the air compressor continues rotating until the maximum pressure value is reached. The unload mode is highly inefficient because it still requires about 20% of its full-electrical load. Replacing the inlet modulation with an unload mode control scheme with a VFD-controlled rotary-screw air compressor saves energy, especially in part-load operation.
Additional Information	WW 9—Electric Motors: Variable Frequency Drives Applications
Primary Area/Process	Air compressors are often found in machine shops where they are used for various maintenance functions. They may also be used to operate hydraulic drives and pumps and, in some instances, pneumatic control. Newer compressed air mixing systems may also rely on compressors.
Productivity Impact	Better constant pressure compressed air can be more productive, since slowdowns in air usage or possible reduction in the need for air are less likely to happen.
Economic Benefit	Payback depends on the operating hours and size of the compressor.
Energy Savings	Energy savings depend on the operating hours and size of the compressor.
Applications and Limitations	None
Practical Notes	None
Other Benefits	Improved consistency of performance of pneumatic equipment.
Stage of Acceptance	Widely accepted by the industry.

B 4—Boiler and Furnace Maintenance

Best Practice	Without proper operation and maintenance, energy consumption can increase by as much as 10 to 20% as the system slowly gets out of adjustment. Maintenance includes keeping physical components in good working order and within design specifications. This entails cleaning heat transfer surfaces, optimizing the air-to-fuel ratio of the burner, keeping vessels and pipes properly insulated, minimizing steam and boiler gas leakage, following good blowdown procedures, monitoring the temperature of stack gases and minimizing steam pressure in keeping with load requirements. Before boiler tune-ups, system diagnostics should be performed, and any deficient equipment brought back to specifications. Changes to design specifications can be made, but system-wide implications of the change must first be considered. Operational practices include equipment adjustments, handling and analysis of boiler log information, and identification of boiler performance goals. Operations and maintenance practices overlap and greatly influence each other.
Additional Information	B 5—Boiler and Furnace System Maintenance; B 6—Implement Burner Management System; B 7—Implement Boiler Stack Economizers
Primary Area/Process	Heating of sludge for anaerobic digestion, process area heating, worker comfort, and meeting thermal needs of treatment processes.
Productivity Impact	Increased reliability and reduced maintenance.
Economic Benefit	Cost savings may be achieved through reduced energy usage.
Energy Savings	Boiler maintenance can achieve boiler energy savings of 2 to 20% depending on existing conditions.
Applications and Limitations	None
Practical Notes	Performing regular operation and maintenance on boilers and furnaces can help to identify maintenance needs prior to failure.
Other Benefits	None
Stage of Acceptance	Well accepted by the industry.

B 5—Boiler and Furnace System Maintenance

Best Practice	Boilers systems need to be inspected for leaks and damaged insulation. Repairing leaks in pipes, connections, and ducting, as well as repairing or replacing poor insulation on boiler jackets, condensate and feedwater tanks, hot water pipes, and air ducts reduce heat loss and energy consumption. A malfunctioning steam trap can waste a large amount of energy.
Additional Information	B 4—Boiler and Furnace Maintenance; B 6—Implement Burner Management System; B 7—Implement Boiler Stack Economizers
Primary Area/Process	Heating of sludge for anaerobic digestion, process area heating, worker comfort, and meeting thermal needs of treatment processes.
Productivity Impact	None
Economic Benefit	Cost savings may be achieved through reduced energy usage.
Energy Savings	Boiler or furnace system maintenance can achieve system-wide savings between 2 and 20%.
Applications and Limitations	None
Practical Notes	Performing regular maintenance on system components can also be a good way of predicting failures or maintenance needs.
Other Benefits	N/A
Stage of Acceptance	Well accepted.

B 6—Implement Burner Management System

Best Practice	Many boilers utilize lo-high-lo control strategies with mechanical linkage systems to maintain adequate fuel/air ratio to support combustion. These controls are inherently inefficient at controlling the fuel/air ratio across the entire burner operating range. Over time, the linkages may go out of calibration or staff either may manually adjust the linkages to positions they feel work for a particular firing rate. By replacing the mechanical linkage system with an electronic servo-based burner management system, fuel/air ratio is more effectively managed across the entire operating range, improving system efficiency. The system continuously monitors and adjusts the fuel to air ratio to ensure complete combustion. In addition, the target temperature or pressure of the boiler (based on outdoor temperature) is monitored by the combustion system. A micro-modulation system provides an easily programmable and flexible means of optimizing combustion across the entire load range of the boiler/burner unit while ensuring that temperature is accurate to within 3°F and pressure to within 1.5 psi.
Additional Information	B 4—Boiler and Furnace Maintenance; B 5—Implement Boiler Stack Economizers
Primary Area/Process	Heating of sludge for anaerobic digestion, process area heating, worker comfort, and meeting thermal needs of treatment processes.
Productivity Impact	Increased reliability and reduced maintenance.
Economic Benefit	Cost savings may be achieved through reduced operational expenses and energy usage.
Energy Savings	Adding a burner management system can increase efficiency by 5 to 10% depending on current control strategies.
Applications and Limitations	None
Practical Notes	None
Other Benefits	N/A
Stage of Acceptance	Well accepted by the industry.

B7—Implement Boiler Stack Economizers

Best Practice	Much of the heat that is not transferred in the boiler to generate hot water or steam goes up the stack with temperatures in the range of 450–500°F. This wasted heat can be recovered and utilized to preheat return water or condensate to the boiler, thus reducing the amount of heat required to heat the water or condensate to its desired temperature or steam pressure. Economizers can be implemented to transfer this wasted energy from the boiler exhaust gas to the boiler return water in the form of “sensible heat.” Sensible heat is created by the transfer of the heat energy of the exhaust gas to boiler feedwater. An economizer captures and redirects sensible heat from the hot flue gas that normally goes up the boiler stack.
Additional Information	B 4—Boiler and Furnace Maintenance; B 5—Boiler and Furnace System Maintenance; B 6—Implement Burner Management System
Primary Area/Process	Heating of sludge for anaerobic digestion, process area heating, worker comfort, and meeting thermal needs of treatment processes.
Productivity Impact	None
Economic Benefit	Cost savings may be achieved through reduced energy usage.
Energy Savings	Adding a standard economizer increases boiler system efficiency by 3 to 5%.
Applications and Limitations	None
Practical Notes	Performing regular maintenance on boilers and furnaces can also be a good way of understanding operations to help predict failures or maintenance needs.
Other Benefits	N/A
Stage of Acceptance	Well accepted in the industry.

B 8—Ventilation Damper and Fan Maintenance

Best Practice	Many ventilation systems use outside air dampers to automatically modulate outside airflow used to condition a space. Outside air dampers can have reliability problems. If the outside air damper becomes stuck open, too much outside air may enter the system and the cooling coils can be overloaded. If it is stuck in the closed position, then adequate ventilation is not provided. As a result, it is important to regularly clean and lubricate the movable parts of a ventilation damper and check the actuator movement periodically to ensure proper operation and to maintain maximum system efficiency. Ventilation and supply fans also require routine maintenance for optimal performance. It is necessary to lubricate bearings, adjust or change fan belts, and clean fan blades on an annual basis.
Additional Information	B 9—Replace Ventilation Air Filters; B 10—Optimize Ventilation System Control Strategies
Primary Area/Process	Buildings
Productivity Impact	Increased reliability, minimizing potential unit failure and downtime.
Economic Benefit	Cost savings may be achieved through reduced energy usage.
Energy Savings	Realized savings are dependent on current operating conditions.
Applications and Limitations	The main purpose of a ventilation system in a WRRF is to supply sufficient outside ventilation air for the dilution of odor-causing contaminants, such as hydrogen sulfide and ammonia. The discharge from the ventilation system is typically treated. Ventilation also plays an important role in conditioning the interior space.
Practical Notes	It is important that any energy efficiency measures that are undertaken do not limit the ventilation system's ability to meet regulatory and safety requirements.
Other Benefits	N/A
Stage of Acceptance	Well accepted.

B 9—Replace Ventilation Air Filters

Best Practice	The ventilation system removes particulates contained in outside air by way of air filters. Particulate accumulation on air filters reduces airflow and increases fan energy consumption. Air filter technology has improved significantly; the use of modern air filters enhances indoor air quality while reducing the total cost of operation if the system is utilizing VFD technology. The cost of the filter can be significant compared to the cost of fan energy required to push air through the filter. The most common enhancement is to replace 2-inch pleated filters with 4-inch extended service pleated filters.
Additional Information	B 8—Ventilation Damper and Fan Maintenance; B 10—Optimize Ventilation System Control Strategies
Primary Area/Process	Buildings
Productivity Impact	None
Economic Benefit	Energy and air quality benefits.
Energy Savings	Realized savings are dependent upon current operating conditions.
Applications and Limitations	Ensure materials of construction and filter design are compatible with air quality.
Practical Notes	None
Other Benefits	N/A
Stage of Acceptance	Widely accepted.

B 10—Optimize Ventilation System Control Strategies

Best Practice	Many WRRF processing buildings were designed utilizing ventilation rates of 12 air changes per hour (ACH) for the dilution of odor-causing and corrosion contaminants, such as hydrogen sulfide and ammonia for life safety and equipment longevity. These ventilation rates are typically maintained continuously 24/7 regardless of whether or not the process area is occupied. Updated codes allow a reduction in the ventilation rate of processing buildings from 12 ACH down to 6 ACH when the buildings are not occupied. This reduced rate typically still provides adequate ventilation to protect equipment from premature corrosion. As a result, there is significant opportunity to reduce energy consumption by reducing the energy required to ventilate the building. A ventilation system control strategy can be developed that allows the minimum ventilation rate of 6 ACH to be achieved during unoccupied periods. When someone enters the building (time independent), the ventilation rate is triggered to ramp up for the safety of the occupant. This ventilation rate is maintained until the occupant leaves the building, at which time the ventilation rate decreases to the minimum 6 ACH.
Additional Information	B 8—Ventilation Damper and Fan Maintenance; B 9—Replace Ventilation Air Filters
Primary Area/Process	Buildings
Productivity Impact	None
Economic Benefit	Cost savings may be achieved through reduced energy usage.
Energy Savings	Savings can range between 20 to 65% of total energy usage.
Applications and Limitations	Careful evaluation of the building use and current codes is required to fully understand this opportunity for energy savings.
Practical Notes	None
Other Benefits	N/A
Stage of Acceptance	Well accepted.

B 11—Clean Lamps and Fixtures

Best Practice	Dirt can accumulate on lamps and fixtures, resulting in a decrease in light output ranging from 5 to 50%. Fixtures and lamps should be washed on a regular schedule using the proper cleaning solution. The frequency of cleaning depends on the amount and type of dirt that is accumulating, whether the fixture is of the ventilated or non-ventilated type, and the location of the lighting. Older style fluorescent lamps last as little as three years; therefore, it may not be necessary to clean between lamp replacements. Newer fluorescent lamps and LEDs can last up to 10 years or more and therefore must be cleaned regularly. Most normal maintenance procedures call for lamps and fixtures to be cleaned on an annual basis but that may be difficult to accomplish with limited staff. Frequent cleaning may be required if the room is exposed to large amounts of dust and grease, if the lamps are directed upward without protection from falling dust, or if the lighting is outside. Many lamps initially provide the same illumination level, but their ability to be economically maintained and to continue their maximum effectiveness is dependent on quality and appropriateness of design. Properly selected fixtures can reduce the need for cleaning or can simplify the cleaning process.
Additional Information	B 12—Replace Inefficient Lighting with High Efficiency Lighting; B 13—Implement Lighting Control
Primary Area/Process	All Lighting.
Productivity Impact	Clean fixtures mean more lighting output and brighter spaces. Better lighting can increase productivity and safety.
Economic Benefit	The practice ensures that the fixtures remain in service for the duration of their expected life, which saves capital funding for when full replacements are necessary.
Energy Savings	None, unless supplemental lighting is currently used.
Applications and Limitations	None
Practical Notes	None
Other Benefits	N/A
Stage of Acceptance	Well accepted.

B 12—Replace Inefficient Lighting with High-Efficiency Lighting

Best Practice	Inefficient incandescent, fluorescent and High Intensity Discharge (HID) type fixtures typically used within buildings such as general use areas, process areas, warehouse and outdoor lighting can be replaced with high efficiency Light Emitting Diode (LED) lighting fixtures, which come in many configurations from screw-in bulbs to lay-in multiple lamp fixtures. Existing light fixtures may also be retrofitted, which may offer an economical solution based on the situation. LED lighting provides a variety of energy and non-energy related benefits. Savings can be achieved from the lower energy consumption of the fixtures. Also, LED fixtures have a longer life expectancy than other outdated technologies. SMART lighting fixtures are also available with integrated control and metering capacities, making replacement of lighting fixtures with lighting controls easier and less expensive than utilizing separate lighting control systems.
Additional Information	B 11—Clean Lamps and Fixtures; B 13—Implement Lighting Control
Primary Area/Process	Buildings, process areas, hallways, high bay applications, offices and parking lots.
Productivity Impact	Lighting quality can have significant impacts on productivity.
Economic Benefit	Payback depends on the number and type of lights replaced, which is typically less than four years.
Energy Savings	Energy savings depend on the number and type of lights being replaced, but typical lighting projects can reduce the electrical lighting energy needed by 30% or more.
Applications and Limitations	Look for the ENERGY STAR® label and Consortium for Energy Efficiency (CEE) qualified fixtures on replacement lighting.
Practical Notes	Lighting projects usually have a short simple payback period and can often be used to help finance additional energy work.
Other Benefits	Benefits realized by the occupants are color temperature control, instant start capabilities in a variety of environments, even light distribution, and more effective directional light. Unlike CFLs, which contain mercury, LEDs contain no toxic chemicals to be concerned with during disposal.
Stage of Acceptance	Generally accepted in the industry.

B13—Implement Lighting Control

Best Practice	In addition to replacing inefficient light fixtures with high-efficiency light fixtures, lighting controls offer additional energy savings by reducing the periods of operation or light output of fixtures. Common controls that are easily retrofitted on existing or replaced lighting fixtures include occupancy sensors and manual dimming. Less common controls that require additional design or modifications include daylight harvesting in areas with large quantities of available daylight and bi-level switching in stairways. These control measures implemented in combination can yield substantial savings.
Additional Information	B 11—Clean Lamps and Fixtures; B 12—Replace Inefficient Lighting with High Efficiency Lighting
Primary Area/Process	Buildings, process areas, hallways, high bay applications, offices.
Productivity Impact	None
Economic Benefit	Energy and air quality benefits.
Energy Savings	Energy savings depend on the number and type of lights being controlled, but typically can reduce the electrical lighting energy required by 15% or more above lighting fixture replacement alone.
Applications and Limitations	Limited application in high-traffic areas due to excessive cycling of lighting fixtures, which can decrease fixture life expectancy.
Practical Notes	None
Other Benefits	N/A
Stage of Acceptance	Widely accepted.

4 References

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
<http://www.ashrae.org/>

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New York State Energy Research and Development Authority: nyscrda.ny.gov

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US EPA's EnergySTAR Portfolio Manager Platform:
http://www.energystar.gov/index.cfm?c=eligibility.bus_portfoliomanager_eligibility

US Department of Energy: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

US Green Building Council: <http://www.usgbc.org>

Water and Wastewater Energy Best Practice Guidebook provided by Focus on Energy, prepared by Science Applications International Corporation (SAIC), December 2006

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Appendix A. Understanding the Electric Bill

As an industrial or commercial electricity user, a number of items can influence the rate that is paid for electricity.

Service classification—most water and wastewater plants are SC-3.

Supply voltage—dependent on what size of equipment is at the facility.

Load zone—geographical area where large amounts of power are drawn by end users.

Rate Structure—negotiated costs per kilowatt-hours use, per kilowatt demand, how demand is charged, other fees, etc.

Usage patterns—on-peak vs. off-peak, fixed price for first fixed number of kilowatt-hours.

A.1 Basic Terminology on Bill

Electricity at most facilities is billed to account for both demand and consumption.

- **Consumption Charge** based on electricity use (dollars/kilowatt-hours)
- **Demand Charge** typically based on peak 15-minute demand during each month (dollars/kilowatt-hours)

Note that the demand charge can be billed on the maximum demand for that month or the maximum demand over the previous 12 months. It depends on the billing arrangement for specific utilities. The following pages present a sample electric bill with explanation of the different components.



SERVICE FOR
JOHN SMITH COMPANY
 1010 ANY STREET
 ANYTOWN NY 99999

BILLING PERIOD
 Feb 18, 2016 to Mar 21, 2016
 ACCOUNT NUMBER
 99999-99999

PAGE **1 of 4**
PLEASE PAY BY
 Apr 15, 2016
AMOUNT DUE
\$ 2,276.36

www.nationalgridus.com
 C & I BUSINESS TEAM M-F 8-5
1-800-664-6729

AUTOMATED SERVICES
1-888-932-0301

GAS EMERGENCIES
1-800-892-2345
(Does not replace 911 emergency medical service)

OUTAGE AND ELECTRIC EMERGENCIES
1-800-867-5222

CORRESPONDENCE ADDRESS
300 Erie Blvd West
Syracuse, NY 13202

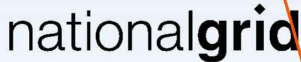
DATE BILL ISSUED
Mar 22, 2016
Enrollment Information

To enroll with a supplier or change to another supplier, you will need the following information about your account:
 Loadzone Central
 Acct No: 99999-99999 Cycle: 16, TWIN

Electric Usage		Gas Usage	
Month	kWh	Month	Therms
Apr 15	800	Apr 15	89
May 15	4480	May 15	135
Jun 15	3520	Jun 15	25
Jul 15	8960	Jul 15	04
Aug 15	5760	Aug 15	00
Sep 15	5280	Sep 15	01
Oct 15	2320	Oct 15	42
Nov 15	2160	Nov 15	245
Dec 15	3200	Dec 15	417
Jan 16	4000	Jan 16	783
Feb 16	4720	Feb 16	1073
Mar 16	4800	Mar 16	1023

Billed Demand Last 12 months

Minimum	11.2
Maximum	57.6
Average	26.1333



300 Erie Blvd West
 Syracuse NY 13202-0960

▶ DID YOU FORGET? ◀

The total amount due includes an unpaid balance from a previous bill. If you have already paid this balance, please disregard this message. Thank You.

ACCOUNT BALANCE

Previous Balance	2,057.68
Payment Received on FEB 22 (ACH)	- 924.03
Balance Forward	1,133.65
Current Charges	+ 1,142.71
Amount Due ▶	\$ 2,276.36

To avoid late payment charges of 1.5%, \$ 2,276.36 must be received by Apr 15 2016.

SUMMARY OF CURRENT CHARGES

	DELIVERY SERVICES	SUPPLY SERVICES	OTHER CHARGES/ ADJUSTMENTS	TOTAL
Electric Service	372.24	119.25		491.49
Gas Service	277.42	356.80		634.22
Other Charges/Adjustments			17.00	17.00
Total Current Charges	\$ 649.66	\$ 476.05	\$ 17.00	\$ 1,142.71

📧 Save time and money! Sign up for paperless billing and receive a \$ 0.40 credit on your monthly bill. Visit our website to enroll today.

🔧 **Payment concerns?** We are here to help. To learn about solutions to help you take control of your energy use and bills, visit www.ngrid.com/billhelp.

★ **WILL WE BE ABLE TO REACH YOU DURING A POWER OUTAGE?:** During a power outage, phones with a direct link to a local phone line are able to operate. Phones that are **not** directly linked (for example, wireless phones with answering machines) need electricity to make/receive calls. If you would like to register another phone number, such as a cell phone, as your account's primary phone number, please go to www.nationalgrid.com/myaccount to update your information so that we may be able to reach you with important information during power outages.

KEEP THIS PORTION FOR YOUR RECORDS.

RETURN THIS PORTION WITH YOUR PAYMENT.

ACCOUNT NUMBER	PLEASE PAY BY	AMOUNT DUE
99999-99999	Apr 15, 2016	\$ 2,276.36 <i>includes amount past due</i>

Electric Usage History:
 This will be important information to collect energy use when developing a baseline.

▶ DID YOU FORGET ? ◀

ENTER AMOUNT ENCLOSED



Write account number on check and make payable to National Grid

*AUTO**SCH 5-DIGIT 13203
 JOHN SMITH COMPANY
 1010 ANY STREET
 ANYTOWN NY 99999

030612

NATIONAL GRID
 PO BOX 11742
 NEWARK NJ 07101-4742



SERVICE FOR
JOHN SMITH COMPANY
 1010 ANY STREET
 ANYTOWN NY 99999

BILLING PERIOD
 Feb 18, 2016 to Mar 21, 2016

PAGE 2 of 4

ACCOUNT NUMBER **PLEASE PAY BY** **AMOUNT DUE**
 99999-99999 Apr 15, 2016 **\$ 2,276.36**

Electricity Delivery: Charges for bringing electricity to your premises regardless of supplier.

kWh: The unit of electricity usage measured by your meter. One kilowatt-hour (kWh) equals 1000 watts-hours, and will light a 100-watt bulb for 10 hours. The number of kWhs is used to determine the electricity charges on your bill.

Choosing an Energy Supplier You can choose who supplies your energy. No matter which energy supplier you choose, National Grid will continue to deliver energy to you safely, efficiently and reliably. We will also continue to provide your customer service, including emergency response and storm restoration. National Grid is dedicated to creating an open energy market that lets you choose from a variety of competitive energy suppliers, who may offer different pricing options. For information on authorized energy suppliers and how to choose, please visit us online at ngrid.com/unyenergychoice

DETAIL OF CURRENT CHARGES

Delivery Services

Electricity Delivery

kW: The instantaneous power, corresponding to the total operating load, typically based on the peak 15-minute demand during each month.

Type of Service	Current Reading	-	Previous Reading	=	Difference	x	Meter Multiplier	=	Total Usage
Energy	2055 Actual		1995 Actual		60		80		4800 kWh
Total Energy Usage									4800 kWh
Billed Energy Usage									4800 kWh
Demand	11.91 Actual		11.63 Actual		0.28		80		22.4 kW
Total Demand Usage									22.4 kW
Billed Demand Usage									22.4 kW

Electric Service Classification: Classification determines the rate structure that might differ according to time of use.

METER NUMBER 12345678 NEXT SCHEDULED READ DATE ON OR ABOUT Apr 22
 SERVICE PERIOD Feb 18 - Mar 21 NUMBER OF DAYS IN PERIOD 32 METERING TYPE Secondary
 RATE Electric SC2D VOLTAGE DELIVERY LEVEL 0 - 2.2 kv

Customer charge: A charge to cover costs for meter reading, billing, equipment, and maintenance. This charge is the same regardless of how much energy is used during the billing period.

Customer									52.52
Demand	10.5134375	x	22.4 kW						235.51
SBC	0.0066138	x	4800 kWh						31.74
Incr State Assessment	0.18	x	22.4 kW						4.03
Legacy Transition Chrg	0.003232	x	4800 kWh						15.51
Transmission Rev Adj	-0.00285	x	4800 kWh						-13.68
RDM	0.85	x	22.4 kW						19.04
Sales Tax	8.0 %								27.57
Total Electricity Delivery									\$ 372.24

Demand charge: The demand charge is designed to compensate the utility for the fixed costs of equipment required to meet the demand. Note that the demand charge can be billed on the maximum demand for that month or the maximum demand over the previous 12 months. It depends on the billing arrangement for specific utilities.

Demand Costs: A significant portion of the overall bill is related to demand costs.

System Benefits Charge (SBC): A charge which funds a number of initiatives, including energy efficiency programs, energy research & development, and other clean energy activities.

Gas Delivery

Service Period	No. of days	Current Reading	-	Previous Reading	=	Measured CCF	x	Therm Factor	=	Therms Used
Feb 18 - Mar 21	32	6449 Actual		5454 Actual		995		1.02858		1023

METER NUMBER 12345678 NEXT SCHEDULED READ DATE ON OR ABOUT Apr 22
 RATE Gas SC2 Small Gen Comm Heat

www.nationalgridus.com



**High energy user?
 Consider Time-of-Use.**

Depending on your electricity usage patterns, your electricity bills may be lower on Time-of-Use (TOU) Service Classification 1C (SC-1C) rate than on standard residential service (SC-1).

SC-1C customers pay a higher basic service charge—currently \$30 per billing period—and a lower delivery charge than on standard residential service. However, these customers will pay more per kilowatt-hour for electricity supply used during on-peak periods. In return, they pay lower rates for electricity supply during off-peak periods, when the demand for electricity is lower.

If your usage is greater than 980 kWh and you have the ability to shift at least 12 percent of your usage to shoulder-peak hours and 80 percent of your usage to the off-season/off-peak hours, you may benefit from this rate.

Electricity Supply: The price of electricity supply used during the billing period. If you choose an alternate supplier, the price will reflect what you agree upon with that supplier.

On-peak hours are:

- ▶ December, January, February: 5 p.m. to 8 p.m. on weekdays
- ▶ June, July, August: 11 a.m. to 5 p.m. on weekdays

Shoulder-peak hours are:

- ▶ December, January, February: 9 a.m. to 5 p.m. on weekdays
- ▶ June, July, August: 8 a.m. to 11 a.m. and 5 p.m. to 8 p.m. on weekdays

Off-season/off-peak hours are:

- ▶ December, January, February: 8 p.m. to 9 a.m. weekdays; all hours weekends
- ▶ June, July, August: 8 p.m. to 8 a.m. weekdays; all hours weekends
- ▶ All hours in the fall months (September, October and November) and spring months (March, April and May)
- ▶ All hours on Dec. 25, Jan. 1, and July 4

Basic Service Charge (including first 3 therms)		24.27
Next 277 Therms	0.29744 x 277 therms	82.39
Over/Last 743 Therms	0.17302 x 743 therms	128.55
Adjustment for Changes from Normal Weather		36.32
Delivery Service Adj(s)	-0.03218 x 1023 therms	-32.92
System Benefits Charge	0.01324312 x 1023 therms	13.55
Incr State Assessment	0.0046 x 1023 therms	4.71
Sales Tax	8.0 %	20.55
Total Gas Delivery		\$ 277.42
Total Delivery Services		\$ 649.66

Supply Services

Electricity Supply

SUPPLIER National Grid

Electricity Supply	0.01978 x 4800 kWh	94.94
Merchant Function	0.00030999 x 4800 kWh	1.49
ESRM	0.002915 x 4800 kWh	13.99
Sales Tax	8.0 %	8.83
Total Electricity Supply		\$ 119.25

Gas Supply

SUPPLIER National Grid

Gas Supply	0.31096624 x 1023 therms	318.11
Merchant Function	0.01199155 x 1023 therms	12.26
Sales Tax	8.0 %	26.43
Total Gas Supply		\$ 356.80
Total Supply Services		\$ 476.05

Other Charges/Adjustments

Late Payment Charges		17.00
Total Other Charges/Adjustments		\$ 17.00

For Your Information

We want you to easily understand your bill, the terms we use and the charges that appear. Following is a brief explanation of items that appear on your bill, as well as payment programs and billing services we offer. If you have questions or want more detailed explanations, please visit our website at www.nationalgrid.com or call 1-800-642-4272.

**Paying Your Bill/
Payment Options**

- **DirectPay:** If you choose, National Grid will automatically withdraw your monthly bill payment from your checking or savings account. You will avoid the inconvenience of check writing, stamps, mailing and due dates. Your service bill will indicate your energy usage and the date of your next automatic withdrawal.
 - **By Mail:** Send us your payment in the envelope provided with your bill. For your protection, please do not send cash. Put your 10-digit account number on your check or money order and include your bill stub. Please do not staple or paper clip your check to the stub.
 - **In Person:** Pay at an authorized payment location by cash or check. Please bring your bill with you. Most locations charge a fee for providing this service. For the payment locations nearest you, visit our website or contact us.
 - **Online:** Enroll online to receive and pay your bill online. The online function will begin with the next billing cycle following your enrollment.
 - **Late Payment Charge:** To avoid Late Payment Charges, your payment must be received by the date shown on the front of the bill.
- Billing Credits**
- Paperless Billing Credit:** A credit provided to Customers who elect to receive their bills electronically through the Company's Online Bill-Pay Program.
- Outage Credit :** A credit issued by the company in case of a prolonged electric service outage.

Charges

Charges for electric or gas service are based on rates or prices approved by the New York State Public Service Commission (PSC). When changes in prices are approved by the PSC, information will be included with your bill. Complete price schedules are available on our website or by contacting us. National Grid reserves the right to upwardly adjust a previously issued bill or back bill.

Basic Service: A charge to cover costs for meter reading, billing, equipment and maintenance. This charge is the same regardless of how much energy is used during the billing period.

Tariff Surcharge: New York State and many local municipalities impose taxes on National Grid's revenue. These operating costs are recovered through a tariff surcharge applied to all rates and charges and may vary among taxing municipalities within the National Grid system area.

Sales Tax: In some areas National Grid is required to collect state and local sales taxes. Some school districts also impose taxes.

Incremental State Assessment

Surcharge/Credit: A surcharge collected on behalf of New York State in accordance with Public Service Law, Section 18-a which established the Temporary State Energy and Utility Service Conservation Assessment.

Merchant Function Charge: A charge for the

Electric Service

kWh: The unit of electricity usage measured by your meter. One kilowatt-hour(kWh) is 1000 watts-hours, and will light a 100-watt bulb for 10 hours. The number of kWhs is used to determine the electricity charges on your bill.

Meter Multiplier: Due to their design, some meters record a fraction of the total usage. The multiplier is used to convert the recorded meter reading on these types of meters to total actual consumption.

CCF: The unit of gas volume (100 cubic feet) as measured by your meter.

Therm: A unit of heat content equal to 100,000 British Thermal Units (BTU). A BTU represents the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. The number of CCFs is multiplied by a conversion factor to determine the therms used. The number of therms is used to determine the gas charges on your bill.

Gas Service

Delivery: National Grid's charges for bringing electricity from your supplier to your premise, regardless of supplier.

Legacy Transition Charge (LTC): All delivery service customers are billed the cost or benefit of electricity supply contracts the Company entered prior to June 1, 2001. Residential customers also receive the benefit of low cost hydropower and a discount payment from the New York Power Authority

Capacity Tag: Your adjusted electricity demand at the hour of the New York Control Area peak load in the most recent 12 month period ending May 1.

SBC: These charges reflect costs associated with mandated public policy programs, such as energy efficiency.

Revenue Decoupling Mechanism ("RDM") : Reconciles actual billed delivery service revenues to annual target revenues. Delivery service revenues above target are refunded to customers. Target revenues above actual delivery service revenues are collected from customers.

Transmission Revenue Adjustment: Reconciles wholesale transmission service revenue to the forecasted transmission service revenue embedded in electric delivery rates. Transmission service revenues above those forecasted are credited to customers. Forecast revenues above actual revenues are collected from customers.

Electricity Supply: The price of electricity supply used during the billing period. If you choose an alternate supplier, the price will be what you agree upon with that supplier.

Electricity Supply Reconciliation Mechanism (ESRM): Reconciles National Grid's electricity supply service revenues to the cost of Company-purchased electricity. Costs above revenues are recovered from customers. Revenues above costs are credited to customers.

Gas Service

National Grid Gas Delivery Service Charge: National Grid's charges for transporting gas across its distribution system to your premise, regardless of supplier.

Adjustment for changes from normal weather: A mechanism that adjusts customers' gas bills due to variations from normal weather during the heating months, October through May.

System Benefits Charge: A charge to reflect costs associated with certain mandated public policy programs, such as energy efficiency programs.

Gas Supply: A charge to reflect the Company's actual cost to purchase gas from suppliers and transporting the gas to the Company's distribution system. If you choose an alternate supplier, the price will be what you agree upon with that supplier.

Delivery Service Adjustment: A collection of surcharges and credits consisting of a Pipeline Refund, Net Revenue Sharing Adjustment, Research & Development Surcharge, Revenue Decoupling Mechanism Adjustment and Deferral Credit.

Estimating Your Usage

When we are unable to obtain a reading, we estimate your usage based on your past usage, taking current weather conditions into account. Because our meters keep a continuous record of usage, any difference between estimated and actual usage is reconciled with the next meter reading. To avoid estimated readings, you can take your own reading on or just before the scheduled date shown on your bill and call it in at 1-888-932-0301.

For more information, visit us at: www.nationalgrid.com or call 1-800-642-4272. Customers with problems paying their National Grid bill should call 1-800-443-1837.

Appendix B. Example Spreadsheet Showing Baseline of Energy Use

EQUIPMENT	Power	Unit	Variable Speed	Operation	Unit	Usage	Unit	Peak Demand	Unit
Comminutor	0.5	hp	N	8,760	hrs/yr	3,267	kWh/yr	0.4	kW
Aerator									
Full Speed	5	hp	Y	4,380	hrs/yr	16,337	kWh/yr	3.7	kW
Half Speed	2.5	hp	Y	4,380	hrs/yr	8,169	kWh/yr	1.9	kW
Clarifier	0.5	hp	N	8,760	hrs/yr	3,267	kWh/yr	0.4	kW
Hypo pump	0.33	hp	N	8,760	hrs/yr	2,157	kWh/yr	0.2	kW
Sludge Pump	2	hp	N	8,760	hrs/yr	13,070	kWh/yr	1.5	kW
Sump pump	0.5	hp	N	4,380	hrs/yr	1,634	kWh/yr	0.4	kW
Lights	11	kW	N	4,380	hrs/yr	48,180	kWh/yr	8.2	kW
Grinder	0.5	hp	N	8,760	hrs/yr	3,267	kWh/yr	0.4	kW
Unit heaters	2	kW	N	5,840	hrs/yr	11,680	kWh/yr	1.5	kW

Appendix C. Economic Evaluation Methods

To determine whether an energy efficiency improvement project will be cost effective, most municipalities consider the “Simple Payback” (SPB) or the “Life Cycle Cost” (LCC). Typically, for smaller projects involving equipment replacement and/or low up-front capital costs, with low maintenance costs, using the SPB method is appropriate. However, for larger projects involving significant up-front capital costs, multiple cost factors and variations in annual cash flow, LCC analysis is preferred.

C.1 Simple Payback

The SPB method calculates the length of time over which cumulative energy savings and other project benefits will be equal to (or “payback”) the initial project investment. To calculate the SPB, divide the total project cost by the total expected benefit.

$$SPB(yr) = \frac{Cost_of_project(\$)}{Annual_savings(\$ / yr)}$$

For example, assume that a facility is evaluating Project A: whether to replace their motors with more efficient models. If the new motors cost \$200,000 and are expected to reduce energy costs by \$100,000 per year and last for five years before another \$200,000 motor replacement is needed, then the SPB for Project A is two years.

C.2 Life Cycle Cost

LCC analysis considers the initial cost of the project as well as all of the costs and benefits over the lifetime of the project. The LCC approach incorporates the time value of money, the volatility of utility costs and other factors such as operation and maintenance or other costs.

$$LCCSavings = LCC(Current_process) - LCC(New_process)$$

where:

$$LCC(Current_process) = \sum AnnualCosts - \sum AnnualSavings$$

$$LCC(New_process) = CapitalCost + \sum AnnualCosts - \sum AnnualSavings$$

For example, assume the same facility is evaluating Project B: whether to use a new treatment process which will cost \$700,000 in the first year, with replacement costs of \$200,000 every five years. Project B is expected to save the facility \$184,000 per year for 20 years. The SPB of this project is 3.8 years. On first look, Project A is more appealing with a SPB of two years versus nearly four years for Project B. However, Project B will generate more savings over time. Assuming an interest rate of 7% and an escalation rate of 3%, the LCC of Project A saves \$660,000 in today’s dollars whereas Project B saves \$1,300,000—a difference of \$650,000.

Backup calculations for both examples are provided in the following pages.

Note: The examples provided are an oversimplification provided for the purpose of showing the payback and life-cycle costs calculations. The examples do not take into consideration labor and parts costs over the life of the project.

The U.S. Environmental Protection Agency (EPA) *Energy Star* Tools and Resources Library (http://www.energystar.gov/index.cfm?c=tools_resources.bus_energy_management_tools_resources) provides links to various *Financial Evaluation Tools* including a *Cash Flow Opportunity Calculator* (a *Microsoft Excel-based tool*) to help decision-makers to evaluate the benefits of installing energy efficient equipment.

The US Department of Energy's *Federal Energy Management Program (FEMP)* offers many resources to assist with Life-Cycle Cost Analysis (<https://www.energy.gov/eere/femp/federal-energy-management-program>) including *FEMP's Building Life-Cycle Cost Software*, training opportunities and a *Life-Cycle Costing Manual*.

LIFE CYCLE COST EXAMPLE - PROJECT A

Interest Rate = $i = 7.0\%$
 Escalation Rate = $e = 3.0\%$

Year (n)	PROJECT A				
	Capital Cost	Replacement Cost	Energy Savings (Annual)	Total Annual Cost	PW Cost
0	\$200,000			\$200,000	\$200,000
1			-\$100,000	-\$100,000	-\$93,458
2			-\$106,090	-\$106,090	-\$92,663
3			-\$109,273	-\$109,273	-\$89,199
4			-\$112,551	-\$112,551	-\$85,865
5		\$231,855	-\$115,927	\$115,927	\$82,655
6			-\$119,405	-\$119,405	-\$79,565
7			-\$122,987	-\$122,987	-\$76,590
8			-\$126,677	-\$126,677	-\$73,727
9			-\$130,477	-\$130,477	-\$70,971
10		\$268,783	-\$134,392	\$134,392	\$68,318
11			-\$138,423	-\$138,423	-\$65,764
12			-\$142,576	-\$142,576	-\$63,305
13			-\$146,853	-\$146,853	-\$60,939
14			-\$151,259	-\$151,259	-\$58,661
15		\$311,593	-\$155,797	\$155,797	\$56,468
16			-\$160,471	-\$160,471	-\$54,357
17			-\$165,285	-\$165,285	-\$52,325
18			-\$170,243	-\$170,243	-\$50,369
19			-\$175,351	-\$175,351	-\$48,486
20		\$361,222	-\$180,611	\$180,611	\$46,673
					-\$662,140
Future Annual Cost = Present Annual Cost x (1 + Escalation Rate) ^{Year} = $A_0(1+e)^n$ (present annual costs). Present Worth Cost = PW = Future Annual Cost / (1 + Interest Rate) ^{Year} = $F / (1 + i)^n$					

LIFE CYCLE COST EXAMPLE - PROJECT B

Interest Rate = $i = 7.0\%$
 Escalation Rate = $e = 3.0\%$

Year (n)	PROJECT B				
	Capital Cost	Replacement Cost	Energy Savings (Annual)	Total Annual Cost	PW Cost
0	\$700,000			\$700,000	\$700,000
1			-\$184,000	-\$184,000	-\$171,963
2			-\$195,206	-\$195,206	-\$170,500
3			-\$201,062	-\$201,062	-\$164,126
4			-\$207,094	-\$207,094	-\$157,991
5		\$231,855	-\$213,306	\$18,548	\$13,225
6			-\$219,706	-\$219,706	-\$146,399
7			-\$226,297	-\$226,297	-\$140,926
8			-\$233,086	-\$233,086	-\$135,658
9			-\$240,078	-\$240,078	-\$130,587
10		\$268,783	-\$247,281	\$21,503	\$10,931
11			-\$254,699	-\$254,699	-\$121,006
12			-\$262,340	-\$262,340	-\$116,482
13			-\$270,210	-\$270,210	-\$112,128
14			-\$278,317	-\$278,317	-\$107,936
15		\$311,593	-\$286,666	\$24,927	\$9,035
16			-\$295,266	-\$295,266	-\$100,017
17			-\$304,124	-\$304,124	-\$96,278
18			-\$313,248	-\$313,248	-\$92,679
19			-\$322,645	-\$322,645	-\$89,214
20		\$361,222	-\$332,324	\$28,898	\$7,468
					-\$1,313,240
Future Annual Cost = Present Annual Cost x (1 + Escalation Rate) ^{Year} = $A_0(1+e)^n$ (present annual costs). Present Worth Cost = PW = Future Annual Cost / (1 + Interest Rate) ^{Year} = $F / (1 + i)^n$					



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